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ORIGINAL ARTICLES.

I.—The Morphology of *Triarthrus*.[1]

By C. E. Beecher,

Of Yale Museum, New Haven, Conn., U.S.A.

(PLATE IX.)

MOST of the recent advances in the knowledge of trilobite-structure have come from the study of *Triarthrus*. Since Valiant's discovery of the antennæ, and its announcement by Matthew in 1893, the writer has published a series of papers on the detailed structure of this trilobite. Much time has also been spent in carefully working out the numerous specimens from the abundant material in the Yale Museum. Altogether upwards of five hundred individuals with appendages more or less complete have been investigated; and at the present time, it may safely be said that the important exoskeletal features have been seen and described.[2]

Notwithstanding the amount of information regarding the details of the various organs, very little has been shown illustrating the general appearance of the animal with the appendages in a natural and lifelike position, and it is one object of the present article to supply this deficiency.

Several specimens have been lately developed which preserve not only the appendages in great perfection, but also show them extended and disposed in a very lifelike manner. No new structural points are here brought out, yet the representation of the complete animal serves as a summary of present knowledge, and also gives a definite picture of great assistance in forming a conception of general trilobite morphology.

The dorsal view represented on Plate IX is from a camera drawing based upon three specimens of about the same size. One gives the entire series of legs down to the ninth free segment, with the exception of the exopodites of the head, which are supplied from a second individual. In the third specimen, the anterior appendages are bent and irregularly arranged, while from the ninth backward to the end of the pygidium they are complete and uniformly extended. The figure is, therefore, a restoration only in so far as representing the best portions of three individuals.

[1] Reprinted from the American Journal of Science, 4th series, vol. i, No. 4, April 1896, pp. 251–256.

[2] The more important literature relating to the structure of the genus *Triarthrus* is given at the end of the present article; numbers in the text refer to this.

The ventral view, Plate IX, is based mainly upon two very excellent specimens. One was figured on plate iv, vol. xv, of the *American Geologist*, and another, since found, nearly completes the ventral aspect. The under side of the head and pygidium was carefully compared with all the available material, and no attempt was made to supply any characters except as to the exact number of joints in the endopodial cephalic elements and the precise form of the cephalic exopodites, which from every character observed, and from analogy with similar structures elsewhere, were as represented.

So many specimens preserve the appendages in the position shown in the figures, that this must be recognized as natural and one likely to have been assumed by the living animal when extended. Few, however, show the details of the limbs with sufficient clearness to enable one to make out all their joints, and more minute characters.

In comparison with what is now known of the appendages of several other genera of trilobites, especially *Trinucleus*,[1] those of *Triarthrus* seem to have been exceptionally long. On this point Bernard, in a letter to the writer, suggests that "*Triarthrus* must have been a sort of 'Daddy longlegs' among the Trilobites, as *Scutigera* is among the Myriapoda." The entire length of a thoracic leg, including the coxal joint, is nearly equal to the width of the body at that point, and about half the length projects beyond the pleura.

The limbs of the head diminish in length forwards until the anterior pair scarcely extends beyond the border of the cephalon. The anterior thoracic legs are the longest, and there is a gradual shortening backward in the series, especially noticeable after passing the fifth, those at the extremity of the pygidium being about one-ninth the length of the first thoracic leg. Their position is also of interest. At the posterior extremity they point almost directly backwards, while those on the head are directed more or less forwards. Between these two extremes, all the intermediate positions occur in regular order.

The gnathobases, or coxopodites, become more and more specialized anteriorly, growing broader and having their inner edge denticulate, until on the head they function as true manducatory organs. The second pair, however, corresponding to the mandibles of higher crustacea, has not become clearly differentiated from the rest of the series, and apparently has not lost the exo- and endopodial branches.

Few changes of importance can be traced in the exopodites, though the latter are considerably reduced in size on the cephalon. Over the anterior half of the thorax, they functioned as vigorous paddles; and on the pygidium their length and compact arrangement made them overlap each other, thus producing two broad flaps, or fin-like organs. The conclusion cannot be avoided that *Triarthrus* must have been an active creature, and with its rows of endopodites and exopodites it was as fully equipped as the bireme in classic

[1] "Structure and Appendages of *Trinucleus*," C. E. Beecher: Amer. Journ. Science, vol. xlix, April 1895.

navigation. The form of the animal and the multiplicity of locomotor organs were well adapted for rapid motion either along the sea-bottom or through the water.

The youngest and most immature limbs are on the pygidium, and in a young trilobite they are very much like those in the larval *Apus* (4) and are typically phyllopodiform. According to the law of morphogenesis, these limbs may be taken as of phylogenetic value and indicative of the primitive type of limb structure.

The whole series of endopodites anterior to the last two or three show modifications from the phyllopodous type, the change involving progressively from one to all of the endites. The endopodites of the pygidium have a true phyllopodiform structure, and are composed of broad leaf-like joints, wider than long. This character is gradually lost in passing anteriorly, the distal endites being the ones first affected. By the time the anterior pygidial limb is reached, the three distal joints are longitudinally cylindrical. The ninth thoracic endopodite shows a fourth endite becoming cylindrical, and on the first and second thoracic legs even the proximal ones are thus modified, making all the endites of these limbs slender in form.

This gradual modification of a phyllopodiform swimming member into a long, jointed, cylindrical crawling leg deserves more than passing notice, for here, probably, better than in any known recent form, can the process and its significance be studied. No living type of crustacean more nearly conforms to the theoretical archetype of the class than do the trilobites; and as *Triarthrus* belongs to an ancient Cambrian family, it may be expected to retain very primitive characters.

In this genus several causes evidently influenced the modification of the appendages. First may be mentioned the specialization into oral organs of the gnathobases of the head, which would tend toward a reduction of the other portions of the limbs. Next, the assumption of a walking habit would gradually lead to a corresponding adaptation of the anterior thoracic endopodites, this region of the body being naturally the place where they would be most operative. Lastly, any tendency to change the form of the anterior limbs would be accelerated through the greater number of moults they undergo as compared with the abdominal appendages.

Since the anal segment of crustacea contains the formative elements out of which all the trunk segments are successively developed, it may be considered as the same segment in all crustacea, no matter how many nor what kinds of segments may intervene between it and the head. The youngest segment, therefore, is always in the budding zone, just in front of the telson, or terminal somite, and those further anterior and more differentiated are older. This sequential order in the age of the segments and appendages may be greatly obscured in higher forms, so that, as in the Thoracostraca, the last pair of pleopods, forming with the telson the caudal fin, appears at an early stage of the ontogeny. In such cases, as Lang says, "the grade of development and physiological importance of a section of the body or of a pair of limbs in the adult

animal may be recognized by the earlier or later appearance of their rudiments."[1]

In *Triarthrus*, these disturbing factors are hardly to be recognized, for no pair of limbs had an excessive physiological importance over any other pair or series of pairs, and increase progressed regularly by the addition of new members in front of the anal segment. The pygidium, being formed of fused segments, accommodated itself to this kind of growth by pushing forward the series of limbs and by the formation of a new free segment at the posterior end of the thorax. This process of metameric growth continued from the protaspis stage with no free thoracic segments, and successively added segment after segment with corresponding moults, until the full complement was reached, after which the moulting resulted mainly in increase in size. The repetition of moults afforded the chief means by which modifications in the appendages could be brought about.

The earliest protaspis stage shows, from the segmentation of the axis, that there were present five pairs of appendages on the head and two on the pygidium (6). The adult animal has thirteen or fourteen free thoracic segments and six pygidial.[2] Now, so far as is known of trilobite ontogeny, there was never more than one segment added at a single moult, though there is no evidence that there may not have been more moults than segments between the protaspis stage and the finished segmentation. In *Triarthrus*, the average full number of segments was attained by the time the animal reached a length of about 7 mm.: so that the limbs of the anterior thoracic segment in an individual 7 mm. in length, and containing the full complement of fourteen free and six pygidial segments, must have undergone at least seventeen moults. The second thoracic segment, therefore, at this stage of growth would have been moulted sixteen times, the fifth thirteen times, the tenth eight times, and the fourteenth four times. The length of full-grown individuals is from 25 to 40 mm., and to have reached this size a considerable number of additional moults must have occurred, in which all the segments participated alike.

Some mention should be made of the probable method of respiration of *Triarthrus*. No traces of any special organs for this purpose have been found in this genus, and their former existence is very doubtful, especially in view of the perfection of details preserved in various parts of the animal.

The delicacy of the appendages and ventral membrane of trilobites and their rarity of preservation are sufficient demonstration that these portions of the outer integument were of extreme thinness, and therefore perfectly capable of performing the function of respiration. Similar conditions occur in most of the Ostracoda and Copepoda, and also in many of the Cladocera and Cirrepedia, where no special respiratory organs are developed.

[1] "Textbook of Comparative Anatomy," English edition (Bernard), p. 410.

[2] A few individuals of this species (*T. Beecki*) have been observed with one or two additional thoracic segments.—Walcott (11).

The fringes on the exopodites in *Triarthrus* and *Trinucleus* are made up of narrow, oblique, lamellar elements becoming filiform at the ends. Thus, they presented a large surface to the external medium, and partook of the nature of gills. But, as Gegenbaur says, "the functions of respiration and of locomotion are often so closely united that it is difficult to say whether certain forms of these appendages should be regarded as gills, or feet, or both combined."[1] For purposes of locomotion, the limbs of the cephalon and pygidium were of feeble assistance compared with those on the thorax; and in the higher crustacea, these two regions are the ones where the greatest branchial specialization takes place.

References.

1. Beecher, C. E., 1893.—A Larval Form of *Triarthrus*. Amer. Journ. Science, iii, vol. xlvi, pp. 361, 362, November.
2. ——— 1893.—On the Thoracic Legs of *Triarthrus*. Amer. Journ. Science, iii, vol. xlvi, pp. 467–470, December. Abstract of a paper "On the Structure and Development of Trilobites," read before the National Academy of Sciences, November 8th.
3. ——— 1894.—On the Mode of Occurrence, and the Structure and Development, of *Triarthrus Becki*. American Geologist, vol. xiii, pp. 38–43, pl. iii, January. Abstract of a paper "On the Structure and Development of Trilobites," read before the National Academy of Sciences, November 8th, 1893.
4. ——— 1894.—The Appendages of the Pygidium of *Triarthrus*. Amer. Journ. Science, iii, vol. xlvii, pp. 298–300, pl. vii, April. Read before the Conn Acad. Arts and Sci., March 21st.
5. ——— 1895.—Further observations on the Ventral Structure of *Triarthrus*. American Geologist, vol. xv, pp. 91–100, pls. iv, v, February.
6. ——— 1895.—The Larval Stages of Trilobites. American Geologist, vol. xvi, pp. 166–197, pls. viii-x, September.
7. Bernard, H. M., 1894.—The Systematic Position of the Trilobites. Quart. Journ. Geol. Soc. London, vol. L, pp. 411–432, August. Read March 7th.
8. ——— 1895.—Supplementary notes on the Systematic Position of the Trilobites. Quart. Journ. Geol. Soc. London, vol. li, pp. 352–359, August. Read April 24th.
9. ——— 1895.—The Zoological Position of the Trilobites. Science Progress, vol. iv, pp. 33–49, September.
10. Matthew, W. D., 1893.—On Antennæ and other Appendages of *Triarthrus Beckii*. Amer. Journ. Science, vol. xlvi, pp. 121–125, pl. i, August. Read before N. Y. Acad. Sci., May, and published in Trans. N. Y. Acad. Sci., vol. xii, pp. 237–241, pl. viii, July 22nd.
11. Walcott, C. D., 1879.—Fossils of the Utica Slate. Trans. Albany Institute, vol. x, pp. 18–38, pls. i, ii, 1883. Author's extras printed in advance, June, 1879.
12. ——— 1894.—Note on some Appendages of the Trilobites. Proc. Biol. Soc. Washington, vol. ix, pp. 89–97, pl. i, March 30th. Read March 24th. Geological Magazine, n.s., Dec. IV, Vol. I, pp. 246-251, Pl. VIII, June.

Explanation of Plate.

Fig. 1.—*Triarthrus Becki*, Green: dorsal view; showing character and extent of antennules and limbs beyond the carapace. × 2½.

Fig. 2.—*Triarthrus Becki*, Green: ventral view; showing entire series of appendages, together with hypostoma, metastoma, and anal opening. × 2½.

Formation and locality.—Utica Slates, Ordovician: near Rome, New York, U.S.A.

[1] "Elements of Comparative Anatomy," Eng. edit. (Bell and Lankester), p. 241.

II.—On the Identification of the *Acanthoceras mammillatum* and *Hoplites interruptus* Zones at Okeford Fitzpaine, Dorsetshire.

By R. Bullen Newton, F.G.S.

SOME molluscan and other remains obtained by Miss Forbes and Miss Lowndes from a brick-pit exposure at Okeford Fitzpaine, near Shillingstone station, Dorsetshire, have recently been submitted to me for determination. They comprise two series of specimens indicative of the well-known Cretaceous zones of *Acanthoceras mammillatum* and *Hoplites interruptus*. Those from the former or earlier horizon were collected about nine years ago, whereas the others were obtained within the last few weeks. It will be convenient to name the species identified from the *Acanthoceras mammillatum* zone first, then to describe the beds constituting the whole of the section, and lastly to give a list of the fauna from the *Hoplites interruptus* zone.

(A) The *Acanthoceras mammillatum* Zone.

Acanthoceras mammillatum,[1] Schlotheim, sp.
Hoplites Benettianus, J. de C. Sowerby, sp.
Pleuromya plicata, J. de C. Sowerby, sp.
Cucullœa carinata, J. Sowerby, sp.
Ostrea Leymeriei (Deshayes MS.), Leymerie.
Exogyra sinuata,[2] J. Sowerby.

The matrix surrounding these shells is mostly of an argillaceous sandy character, slightly micaceous, and of a brown, grey, or yellowish colour. That associated more particularly with the specimens of *Ostrea* and *Exogyra* exhibits an oolitic structure, the grains of which are heavily charged with hydrated oxide of iron. This fossiliferous bed, containing also some small siliceous pebbles, has a thickness of five feet, and lies about twenty-eight feet from the surface; beneath is a deposit of pure sand, having a depth of three feet, which reposes on a stiff blue clay of, probably, Kimeridge age; at the base of this occurs a sandy rock-formation which possibly belongs to the Corallian period. Immediately above the deposit containing the shells is a seam of brown sandy rock, four feet in depth, succeeded by fifteen feet of a grey-coloured sandy clay (of a bluish tint when damp), with phosphatic nodules interspersed (a section of one showing veins of calcite); both these bear a Lower Gault fauna, characterized by *Hoplites interruptus*, etc. Then follow two unfossiliferous bands—one of brown clay, five feet thick, the other of yellow clay with angular fragments of chert, three feet thick; a foot of subsoil occurring above this completes the section.

[1] This name has been incorrectly written *mammillaris* by many authors, though its original rendering was [*Ammonites*] *mammillatus*.

[2] *E. sinuata* (synonymous with *E. aquila* of Continental authors) is not to be confounded with *E. Couloni*, Defrance (=*subsinuata*, Leymerie), the latter differing not only in specific details, but characterizing a lower horizon, viz. the Hauterivien stage, or the upper part of the Neocomian strata.

In tabular order the beds[1] may be thus arranged:—

		Feet.
	Subsoil	1
	Yellow clay with chert	3
	Brown clay without chert	5
Hoplites interruptus Zone.	Dark-grey coloured, micaceous, and sandy clay with phosphatic nodules; fossiliferous in the lower 4 feet	15
	Brown sandy rock, with fossils in the upper part	4
Acanthoceras mammillatum Zone.	Argillaceous sandy beds, micaceous, and of a brown, grey, or yellowish colour; ferruginous and oolitic; siliceous pebbles interspersed; fossiliferous	5
? Aptian.	Pure sand	3
Kimeridgian.	Stiff blue clay	8 or 10
? Corallian.	Sandy rock.	

Among the great group of the Ammonites characterizing the Cretaceous formation, none is perhaps of more importance than that of *Acanthoceras mammillatum*. As a zonal species it is of the highest value to the geologist, being restricted in its distribution to the topmost stratum of the Folkestone beds, and never occurring either above or below this position in the series.[2] The present discovery, therefore, of the *Acanthoceras mammillatum* zone in Dorsetshire is of interest as establishing its extension more westerly than hitherto recognized. A few years ago Mr. Jukes-Browne called attention (Geological Magazine, 1891, p. 456) to the occurrence of some clays and sands beneath the Gault in Dorsetshire, which were traced for a distance of four or five miles between Twyford and Childe Okeford, and determined as of Lower Greensand or "Vectian" age. The stratigraphical particulars given of these beds appear to correspond so closely with those observed at Okeford Fitzpaine that it is highly probable they refer to the same series of deposits, though, as no palæontological evidence was referred to by Mr. Jukes-Browne, it must remain a little doubtful until a future comparison can take place on the spot. There is, of course, no reason why the beds on the eastern side of the Stour valley should not be continued across the river in a south-westerly direction to Okeford Fitzpaine, and even to other localities further on that are situated near the junction line of the Kimeridge with the Cretaceous rocks (see Geological Survey map of this district, No. xviii).

Opinions were long divided as to whether the *Ac. mammillatum* zone represented the top of the Lower Greensand (Aptian) or the base of the Gault (Albian). The latter view is that generally adopted now, on account of so many species passing up into the true Gault series. The present fossils contain only two forms which

[1] I am greatly indebted to Miss Forbes and Miss Lowndes for supplying me with the details of this section. Unfortunately, only the *Hoplites interruptus* beds are now exposed, the lower part of the section having been filled in.

[2] In Reid and Strahan's "Geology of the Isle of Wight" (Mem. Geol. Survey, 1889, p. 279), *Ac. mammillatum* is stated to have been found in the Chloritic Marl of Mottistone Down, which is probably either a misdetermination or some error has crept in as to the horizon.

survived to later times, viz. *Pleuromya plicata* and *Cucullœa carinata*; the other species are not known in a higher horizon than this zone. *Hoplites Benettianus* appears to be confined to it; whereas *Ostrea Leymeriei* and *Exogyra sinuata*, having been found at Atherfield and in the upper part of the Speeton Cliff, etc., would date their existence from the Rhodanien stage of the Urgonian (or Barremian) epoch. The examples of *Ostrea Leymeriei* are of great size, one of them measuring 221·5 by 180 millimetres, being in excess of the largest known specimen figured by Coquand in his work on the "Ostrea," 1869, pl. lxxi, fig. 6, which measures 180 by 175 mm.

(B) The *Hoplites interruptus* Zone.

The matrix of this zone, as represented at Okeford Fitzpaine, is more sandy than argillaceous, and full of minute specks of mica; in these characters, as well as in its dark-grey colour, it bears a strong resemblance to what obtains in the Lower Gault beds at Black Ven, near Lyme Regis—and *Lima parallela* appears to be equally abundant at both localities.

As this is the first record of Gault fossils from this part of Dorsetshire, the following list of species recently collected by Miss Forbes and Miss Lowndes will, it is hoped, be of special interest:—

PISCES.

Lamma appendiculata, Agassiz, sp.
Synechodus, sp.

CEPHALOPODA.

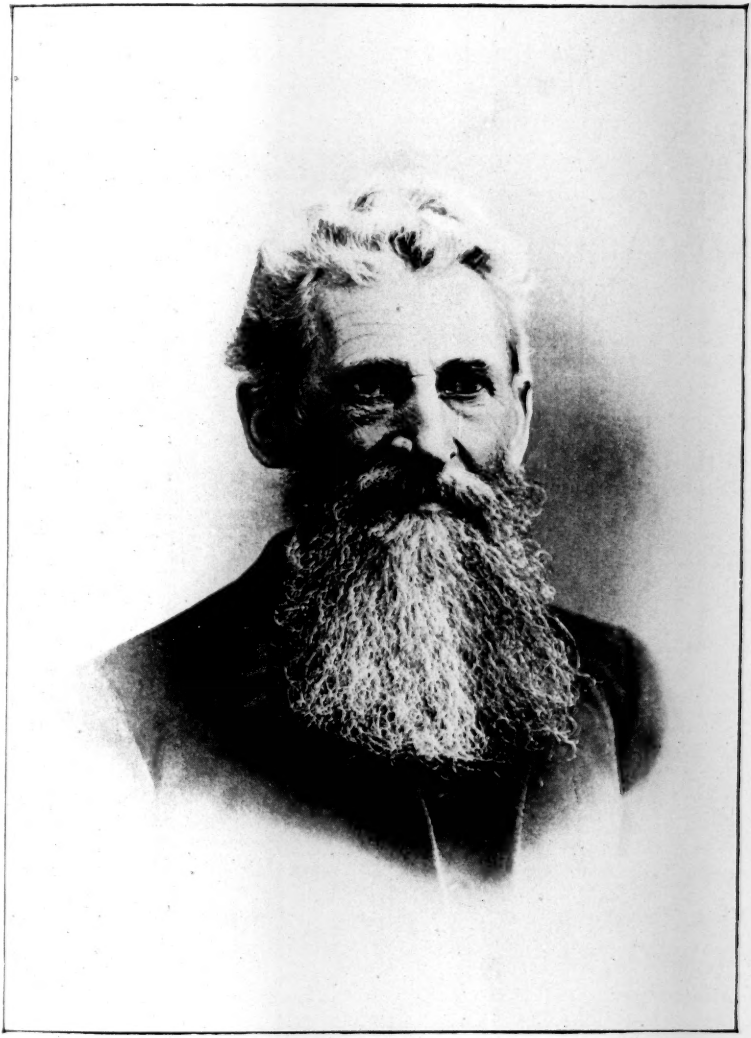
Hamites, sp.
Hoplites interruptus, Bruguière, sp.
Hoplites splendens, J. Sowerby, sp.
Nautilus Clementinus, Orbigny.

GASTEROPODA.

Actæon Dupiniana, Orbigny (allied to).
Anchura carinata, Mantell, sp.
Avellana inflata, J. de C. Sowerby.
Natica Gaultina, Orbigny.
Scala Dupiniana, Orbigny.
Solarium ornatum, J. de C. Sowerby.

LAMELLIBRANCHIATA.

Cucullœa carinata, J. Sowerby, sp.
Entolium orbiculare, J. Sowerby, sp.
Gervillia solenoides, Defrance.
Inoceramus concentricus, Parkinson.
Lima parallela, J. Sowerby, sp.
Mytilus subsimplex, Orbigny (allied to).
Nucula pectinata, J. Sowerby.
Ostrea canaliculata, J. Sowerby, sp.
Pecten, sp.
Pleuromya plicata, J. de C. Sowerby.
Solen Dupinianus, Orbigny.
Thracia simplex, Orbigny, sp.
Trigonia aliæformis, Parkinson.
Trigonia Archiaciana, Orbigny.
Trigonia Fittoni (Deshayes), Leymerie.



CHARLES WACHSMUTH.

1829–1896.

See Obituary, GEOL. MAG., p. 189, *April*, 1896.

ANNELIDA.

Serpula antiquata, J. de C. Sowerby.

PLANTÆ.

Coniferous wood.

In conclusion, the author desires to thank Mr. G. C. Crick, F.G.S., for his assistance in determining the Cephalopods referred to in this paper. Mention should also be made of the fact that the fossils enumerated from these Cretaceous zones are the property of Miss Lowndes, but she has generously consented to give a selection of them to the Geological Department of the British Museum (Natural History), Cromwell Road.

III.—Notes on the "Pleistocene Beds" of the Maltese Islands.

By John H. Cooke, F.G.S., F.L.S.

In August, 1891, I published in the Geological Magazine the results of my work on the Pleistocene beds of Gozo.[1] Since then I have made a careful and systematic survey of the islands, and have discovered and traced out several important beds that had escaped the notice of those who had preceded me in working out the islands' geology. In the following "notes" I have briefly summarized the results in the hope that they may be of use, not only to other students of the geology of the district, but also to the agriculturist, who, by drawing on the resources that they offer, may bring into cultivation much of that portion of the western parts of the islands which from its supposed dearth of soil has hitherto been looked upon as uncultivable. I have elsewhere described this district and its capabilities; there is, therefore, no need for me to enlarge upon that part of the subject here.[2]

St. Paul's Bay Deposits.—The valley at the head of St. Paul's Bay known as Uied tal Puales, as well as the slopes that bound the bay itself, are covered with superficial deposits of varying ages and characters. They comprise calcareous loams, alluvial soils, imperfectly formed limestones, and accumulations of limestone-agglomerates and breccias. St. Paul's Bay owes its origin to a depression between two sets of parallel faults, the faces and faults of which are furrowed with small valleys and gullies. The flood waters from these tributaries have largely assisted in filling up the inequalities of the depressed area with the detrital products of the surrounding plateaux; and the alluvium which has been thus spread over has, in many parts, a thickness of from 15 to 20 feet. Besides these accumulations of residual materials the slopes of the valley sides are, in places, lined with alternating deposits of loam and rock-fragments capped with a compact layer of limestone of a greyish colour.

[1] "Notes on the Pleistocene Beds of Gozo": Geol. Mag., Aug. 1891. p. 348.

[2] J. H. Cooke, "On the Cultivation of *Agava rigida* in Malta": Med. Nat., Nos. 26 and 27, 1894.

The loams are similar to those which occur in most of the plateau valleys of the islands. They are very homogeneous in texture, and are somewhat incoherent. They exhibit no signs of stratification, but lines of bedding are strongly marked. Both these, and the underlying layer of compact rock, contain considerable quantities of land-shells, comprising *Helix aspersa*, *H. Melitensis*, *H. vermicularis*, *Clausilia bidens*, *Rumina decollata*, *Cyclostoma Melitensis*, and *Clausilia sulcatum*; but no mammalian or other remains are present. On the southern slopes, near the head of the bay and in the valley which debouches on Ghain tal Razul, numerous interesting sections are to be seen. On the south-eastern shore, between the main road and the old church, there is an extensive bed of grey, calcareous loam, capped with a layer of fine sand and grit. Like the valley deposits it contains enormous quantities of land-shells, but all of them are broken and beyond identification.

The deposit is distinctly stratified, and it averages five feet in thickness. The most interesting of the beds that occur in this locality are the limestone agglomerates which fringe the shore-line.[1] These agglomerates admit of being divided into two classes, one of which is more ancient than the other; the older of the two is to be seen along the shore, extending from the tower to the cliffs below Selmone Castle. Along the southern shore of the bay it lies unconformably on a considerable area of Upper Coralline Limestone, which has been depressed beneath the sea-level by a secondary fault. This depressed area extends from Cala tal G-gazenin to Ghain tal Razul; and the agglomerates cover it for a distance of about two hundred yards, and fill all of its fissures and surface extravasations. The creek of G-gazenin is bounded on the south-west by a narrow promontory which disappears beneath the waters of the sea in an easterly direction, and reappears at a distance of twenty yards as two small outliers. Both the surfaces of the promontory and of the outliers are covered with the agglomerates. The rock upon which these beds now rest had been much eroded into fissures and pot-holes, prior to the deposition of the agglomerates, but all of these irregularities are now filled with the Pleistocene materials. In places a layer of stalagmite of from one to two inches in thickness serves as a line of demarcation between the beds. The agglomerates consist of a mass of angular, subangular, and rounded rock-fragments, all of which have apparently been derived from the Upper Coralline formation. They are promiscuously intermingled, and are embedded in an exceedingly compact, calcareous and ferruginous earth of a deep red colour. Small veins of calcite traverse the rock in all directions, and the sections are pitted with minute borings the interiors of which are lined with crystals of calcite.

The bedding planes are distinctly marked, but evidences of stratification are not so apparent. The bed is so compact that it is only with difficulty that specimens can be detached from it. Some idea of its compactness and durability may be obtained from the fact

[1] Photographs of these, and of most of the other beds that are referred to in these notes, may be seen in the Library of the Geological Society of London.

that it is at all times being battered by the Mediterranean waters, but though blocks of the underlying limestone have been broken off and hurled by the storm-waves to considerable distances, the agglomerates have been but little affected. The thickness of the deposit averages about four feet. I have made many careful examinations of the bed, but the only trace of organic remains that I could find was a portion of a bone of some mammal which I detached from a mass of the agglomerate which lay on the shore-line immediately below the Scicluna Palace. Similar deposits are to be seen at the head of the bay and on the shore-line of the Melleha road. Below Ghain tal Razul there is another and more recent accumulation of a similar character which averages about 16 feet in thickness. It lies on the shore-line at the mouth of the Razul valley, and unconformably on the Globigerina Limestone. Unlike its more ancient prototype it consists of several distinct beds.

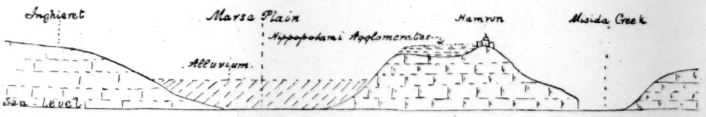
a. The base is composed of silt and fine gravel, intermixed with a few pebbles of Globigerina Limestone of varying sizes and shapes.

b. Above this is a layer of about 15 feet in thickness, consisting of subangular and rounded masses of the Upper Coralline Limestone and of the Globigerina Limestone indiscriminately heaped together and embedded in a loose red earth.

The deposit is roughly stratified, and it is quite unfossiliferous. On the old Melleha road the plateau slopes are covered with considerable quantities of the brecciated loams.

The Hamrun Beds.—These deposits lie on the summit and along the sides of an elevated ridge of the Globigerina Limestone, which lies between the Marsa plain and the Marsamuscetto harbour. The ridge forms the eastern boundary of the Marsa plain, and rises from it with a gradual ascent. It lies immediately opposite to the mouth of the gorge, Uied Kbir, and in a line with Uied Curmi. These two gorges form the main drainage channels of the most extensive catchment basin in Malta.

The height of the summit of the ridge above the Marsa plain varies, the outline being undulatory, and it has a gradual decline toward the head of the Grand Harbour; but the average of the highest points is about forty feet.



A few years ago the whole of the summit of the ridge was laid out in fields, but latterly house-building has progressed so rapidly that the area has now been converted into a densely populated suburb of Valletta. It was whilst the drainage system of the neighbourhood was in process of construction, and the new streets were being laid out, that my attention was first called to the occurrence of these agglomerates, with the molars of *Hippopotami*

Pentlandi embedded in them. The section which was exposed when trenching for the laying of water-pipes in Strada St. Giuseppe is of a very interesting character. The following is the order in which the layers occurred :—

a. Alluvial soil. One foot in thickness.

b. A whitish, highly calcareous loam; very homogeneous, and apparently structureless; plastic and tenacious when wet, but incoherent when dry. It contains a few small fragments of decomposing limestone and numerous land-shells in a good state of preservation. Two feet in thickness.

c. A rich alluvial soil of a reddish colour. It is similar in its general characters to layer *b*, into which it merges by almost imperceptible gradations. One specimen of *Helix pisana* was found. The bed is about two feet in thickness.

d. A layer of angular fragments of Lower Coralline Limestone, together with some decomposing fragments of Globigerina Limestone. The matrix consists of a reddish clay nine inches in thickness.

e. Layer *d* gradually changes in its character towards its base until it passes into a typical conglomerate consisting of rounded pebbles and fragments of bones and molars of *Hippopotami Pentlandi*. The bed was so compact that it was only with the greatest difficulty that the workmen were able to cut through it.

I was not able to ascertain the acreage over which the bed extended, as the trench was but $2\frac{1}{2}$ feet wide. It extended throughout the length of the trench, a distance of 210 feet, and the average thickness was $7\frac{3}{4}$ feet.

The layer of conglomerate was lenticular in shape, thinning out in a south-east and a north-west direction. Its longer axis was at right angles to the mouth of the Kbir gorge, from which it seemed evident that the materials had been laid down at one extremity of the "cone of dispersion" which had been formed on the plain by the drainage waters of the gorge.

The width of the bed is not, however, very great, as in many of the sections which were exposed in the cess-pit and well-cuttings in the vicinity no trace of the conglomerate could be found.

The overlying beds extend for a considerable distance in all directions. The thickness of these layers varies considerably. They often assume a lenticular shape, and have their thin ends dovetailed the one into the other.

In a cutting which was made about fifteen yards to the north of the tower in Strada St. Giuseppe the following beds were exposed :—

a. Alluvial soil. One foot in thickness.

b. An orange-coloured loam, unstratified, and containing an abundance of fossil land-shells. One foot six inches in thickness.

c. An evenly bedded, slightly indurated limestone, which thinned out in a north-westerly direction. It was one foot six inches in thickness, and passed imperceptibly into

d. A light-grey loamy earth, structureless and slightly indurated. It contained a few decomposed fragments of limestone, and two specimens of *Helix pisana*. Three feet in thickness.

e. A layer of subangular fragments of the Lower Limestone, decomposing fragments of Globigerina Limestone, and a few pieces of flint. All of the fragments lay with their flattened sides in a horizontal direction. Eight inches thick.

Layers *b* and *d* are very calcareous, and slightly plastic. They are known among the native workmen by the name of "torba," a kind of clayey earth which is used for making the roofs of houses damp-proof.

All of the layers are very homogeneous, and with the exception of *c*, and *e*, none of them present any evidences of structure. Land-shells (*Helix pisana*) in an entire and a broken condition occur at intervals; but besides these no other organic remains were met with.

Layers *b*, *c*, and *d*, passed imperceptibly the one into the other; but the surface of layer *b*, was eroded into "pipes," all of which were filled up with the alluvium of the layer *a*. Between layer *e*, and the underlying rock the line of demarcation, though perceptible, was not strongly marked owing to the decomposition which the surface had undergone.

Numerous other sections in the neighbourhood were also examined, but the only differences consisted in the varying thicknesses of the layers, and in the total absence of the ossiferous conglomerates.

In none of the beds can it be said that the lines of stratification were of a very pronounced character. In this respect the "torba" layers were puzzling; but when small cubes of these layers were cut out they readily split along their bedding planes. From the character and situation of these deposits, it seems probable that they must have owed their origin to the flood waters which poured down the gorges to which I have already referred.

The traces of lamination which the "torba" beds exhibit show that the periods of deposition had quiet and tranquil phases, just as the coarser materials and the huge pot-hole on the opposite side of the hill, in the garden of Villa Frere, demonstrate that they had tumultuous ones.

The Malak Agglomerates.—The surfaces of the fault terraces at Malak are enveloped with extensive accumulations of angular and subangular boulders firmly embedded in a reddish-yellow loam. These accumulations have been referred to by Dr. Leith Adams, but no attempt was made to classify them. They admit of a tripartite division.

A. Yellowish clays containing small subangular fragments of rock, but without any evidences of organic remains. These lie at the base of the sea-cliffs at the sea-level, and they may be traced from Ras-el-Hamra to Ras-el-Scuda. They lie unconformably on the Upper Coralline Limestone, which in this part of the island has been depressed about 500 feet by the Malak faults.

B. A talus of from six to ten feet in thickness, consisting of angular and subangular boulders of the Lower Coralline Limestone. It inclines at a high angle, and extends down the slopes, overlapping A, to the water's edge. This division is only found between Ras-el-Hamra and Uied-el-Mirhla. Adams[1] found the greater portion of a skull of *Elephas Falconeri*. I have found no organic remains here, but in the deposits at the same horizon which lie to the left of the mouth of Uied-el-Mirhla I obtained several limb-bones, including a portion of a humerus of *Elephas Mnaidra*.

C. Higher up the slopes there occurs a layer of angular rock-fragments embedded in an extremely compact calcareous cement. It is persistent all along the fault terrace, and averages about two feet in thickness. In places it overlaps division B, and it is therefore more recent than either of the other layers. The character of the rock-fragments, which are similar to those contained in divisions A and B, as well as the great compactness of the deposit, prove that it must be of considerable antiquity. Land-shells, chiefly *Helices*, in a broken condition were abundant; but mammalian remains appeared to be absent.

Kammieh and Melleha.—The Pleistocene beds at Kammieh and Melleha may be separated into two well-marked divisions, the lower of which differs but little from the loam-breccias that line the bottoms of the slopes of the valleys in other parts of the islands, while the upper one, though possessing certain distinctive characters of its own, is similar in many respects to the beds at Forn-ir-Rieh and Hammar. The sections which are exposed between Redum ta Kassisu and Redum tal Imgharka on the north-western side of Melleha Bay, along the coast of Ramla ta Chumnia, and Ghain Zeituna on the south-eastern shore, and along the shore-line of Il Ponta tal Circheuna and of L'iscol tal Marfa in the Kammieh peninsula, show that all of the deposits in these regions are identical in character. The deposit at L'iscol tal Marfa is typical. It exhibited the following sequence :—

a. A series of layers of red and yellow, compact gritty limestones, resting unconformably one on the other. The materials vary in character, being sometimes coarse and sometimes fine. They abound with land-shells, principally *Helices*, and also with a stunted brackish-water form of *Cerithium*. As a rule the layers exhibit few traces of structure, but where the materials are the coarsest, evidences of irregular bedding and of stratification are apparent.

b. Beneath these layers and passing abruptly but conformably into them is a seam of subangular and of rounded pebbles, of about two inches in thickness. None of the pebbles exceed the size of a walnut, and the majority are no larger than

[1] A. L. Adams, "The Nile Valley and Malta," p. 174. Edinburgh.

a small nut. The rock-fragments lie with their longer axes parallel to the bedding planes of the deposit, and the shells are intact, thus presenting every appearance of having been formed under comparatively quiet conditions.

It is not, however, persistent throughout all of the deposits in the neighbourhood, but occurs only in those localities where the angle of the slopes, whence the materials were derived, was a moderate one. The rock-fragments have been derived from the Upper Coralline Limestones in the vicinity. Beneath this seam lies another bed of gritty limestone, which is similar in its lithological aspects to the upper members of the series. The materials of which it is composed are rounded, and they are so compactly bound together that freshly fractured surfaces present a homogeneous appearance. This portion of the bed averages three feet in thickness, and it extends along the shore for about a mile. *Helices* and a minute *Cerithium* are extremely abundant. Spratt has noted the occurrence of the tests and spines of echinoderms in similar deposits at the head of the bay, but it was not my fortune to meet with any. This series, which I shall call the Upper series, averages about ten feet in thickness.

Beneath this is the lower portion, which lies unconformably on a bed of brecciated loam, consisting of a heterogeneous assortment of pebbles and angular fragments of limestone disseminated throughout the mass. The loamy matrix is made up of finely comminuted clayey particles intermixed with a large percentage of calcareous rock powder, and an appreciable quantity of ferric oxide. Both in its composition and in its general characters the bed agrees closely with the loam-breccias, to which reference has already been made. It averages about three feet in thickness, and, as it forms the basement of the limestone grits, the rapid degradation that it is undergoing is causing the equally rapid destruction of the beds that overlie it. The shore-line is therefore strewn with huge masses of "grit," which have broken away from the main upper bed in consequence of the wearing away of these loamy foundations. The bed contains an abundance of land-shells, but they are not so well preserved as in the upper stratum.

Besides these shore deposits, there are in the bottom of the depression between Kammieh and Melleha, to the west of Torre Hamra, and along the summit of the peninsula of l'Arasc, considerable accumulations of loose "grit," the products of the degradation of the Pleistocene beds which formerly served as a capping to the Upper Coralline Limestone of the district. Large quantities of it have been scattered by wind action over the Kammieh isthmus; and in places, where the surroundings have been favourable, it has been carried down the slopes on the northern side of the isthmus, and has been formed into terraced beds which are very similar in character to the "grits" around the shores of the bay.

The adjoining fault terrace in Uied-tal-Mistra is likewise covered with some interesting deposits of Pleistocene age. Throughout its

length it is cloaked with indurated loams and agglomerates, which towards the centre extend across the valley and form a broad flat plain between the slopes. In several places on the northern side these accumulations attain a thickness of from 10 to 15 feet, but the average depth is four feet. The beds are analagous in character to the loams in the Dueira, Il Kala, and other elevated districts of the islands, but owing to the difficulties in the way of properly irrigating the district these beds have not been much disturbed by the agriculturist. Near Mizieb-ir-Rih the deposits attain a considerable thickness, and where they have been broken up they have formed a rich, red, fertile soil. They consist of a heterogeneous assemblage of rock-fragments and loam, all of which have been derived from the Miocene beds in the vicinity. In parts, the breccia that has thus been formed is so indurated that it has been cut out in blocks and utilized by the husbandmen for the building of walls and cattle-sheds. The beds attain their greatest thickness in the bottom of the valley near Mizieb-ir-Rih and Hofriet-migdun, but as the slope rises they thin out and disappear. Land-shells, fragmentary and entire, abound, and several fragments of mammalian bones were found, probably *Cervus*. Southward equally interesting sections are to be seen. No part of either Malta or Gozo exhibits so many evidences of stratal disturbance as does that which lies between Karraba and Kammieh. The cliffs are fissured in all directions, and considerable faults have been formed. In the centre of this disturbed region is a talus of red loam and angular and subangular débris of Upper Coralline Limestone origin, which extends from the summit of the cliffs to the sea-shore, a distance of between 250 and 300 feet. It bears a striking resemblance to the elephant beds at Malak, but the only remains that I could discover after many diligent searches were comminuted fragments of *Helices* and other land-shells. All of the plateau valleys exhibit evidences of the presence of similar beds. It will therefore be sufficient if I draw attention to one which, besides being noteworthy in many details, is also easy of access.

The slopes of the Imtarfa plateaux are marked by deposits which are very typical of the superficial beds of the plateau region. They exhibit the following sequence:—

	in.
a. Alluvial soil.	18
b. A slightly indurated red loam, intermixed with subangular boulders	24
c. Friable loam and fine gravel, with remains of broken land-shells.	24

Besides the preceding deposits, which I have described as being the most noteworthy and as being typical, there are numerous other localities in which I have noted patches of Pleistocene beds. All of the bays on the eastern and south-eastern coasts of the island have stratified accumulations of loam and rock-fragments lining their slopes and higher reaches. To the north of Cala di St. Tommaso,

a patch extending over an area of one and a half square miles offers some excellent sections; and between Marsa Scirocco and Delimara Fort there are extensive beds of alluvial material lining the shores and attaining thicknesses of from six to ten feet.

The elephant bed in the Benhisa gap has been described in detail by Dr. Leith Adams, and therefore needs no further remark from me. On the north-eastern shore-line there are several interesting patches deserving of notice.

The valley of St. Julians, St. George's creek, and the cliffs at Sliema and Ghar-id-dud are lined with accumulations of roughly bedded loams and angular débris. At Sliema these accumulations assume the character of a friable ferruginous loam with hard, calcareous, concretionary masses interspersed throughout; or as masses of agglomerate made up of rock-fragments bound together with a compact ferruginous cement and interstratified with stalagmitic layers that often attain a foot in thickness.

I will now briefly summarize the preceding details. The beds may be grouped in three classes—

I. The valley loams and breccias.
II. The agglomerates which are found along the coast-lines and fault-terraces.
III. The ossiferous deposits in the caves and fissures.

The cave deposits have already been described in detail by the late Dr. Leith Adams and myself.[1] I need not, therefore, make any further reference to them here. The valley deposits may be subdivided into the residual and the alluvial beds, which are found on the higher slopes of the plains and plateaux, and the diluvial deposits, which cover the sides and beds of the gorges and valleys. Of the former of these subdivisions, the beds at Dueira, Giurdan, Gebel Ciantar, Imtarfa, Nadur, Tal Mistra, and Tal Asiri are prominent examples. The structural facies of these beds may be thus summed up:—

1. A capping of indurated limestone made up of the finer residual products of the underlying layer.
2. Unstratified layers of angular and subangular rock-fragments. The rock-fragments have always been derived from the Miocene formations in the neighbourhood.
3. Thin interstratified layers of loam and stalagmite. The loams often present evidences of oblique lamination.

In the districts where the angle of the slope is not a high one, as at Imtarfa and Tal Mistra, the basement layer consists of a homogeneous, highly calcareous loam; but where the angle of the slope is a high one the loam is intermixed with angular fragments of rocks, and it assumes a roughly stratified appearance. Where the

[1] Adams, Leith A. L., "Maltese Bone Caves": Geol. Mag., Vol. I, p. 140.
idem. "Fossil Elephants of Malta": Geol. Mag., Vol. II, p. 448.
idem. "Maltese Fossiliferous Caves": Rep. Brit. Assoc. 1886.
idem. "Nile Valley and Malta." Edinburgh, 1870.
Cooke, J. H., "The Har Dalam Cavern, Malta": Proc. Royal Soc., vol. liv, 1893.

intermixture has taken place in about equal proportions more or less distinct traces of bedding are perceptible, but where the rock-fragments or the loam respectively predominate the bed exhibits no definite structure. The alluvial beds are found in the valleys that have long, gentle slopes. These deposits are very uniform in their nature and composition. The rock-fragments that enter so largely into their composition are small in size, and of local origin. They are most numerous in the middle portions of the deposits, and are generally very freely distributed in the divisions that are situated above the middle line. These beds have as their homologues the alluvial calcareous earths which are at present being slowly formed along the valley terraces by the action of rain-wash. Both are similar in composition, and both are devoid of structure. The fossils found in these beds consist of land-shells in a very comminuted condition.

At Dueira, Tal Asiri, Redum Ahmar, Tal Mistra, and San Giorgio, fragments of the limb-bones of ruminants and of horn-cores of a species of *Cervus* were found in comparative abundance. It is a noticeable fact that no plant-remains have been found either in these or in any of the other superficial beds of the islands. But this is to be expected when the broken condition in which the shells and the mammalian remains were found is taken into consideration. The maceration and the rough usage which the plant-remains must have undergone, would have effectually destroyed them long before they could have been deposited with the other materials. And even if the deposition had been accomplished, the loose, porous nature of the beds is such as to have been highly favourable to their rapid decomposition. At the debouchures of all of the larger gorges plains of considerable area occur consisting of stratified deposits of alluvial material. These have been spread out in a fan-shaped form, the apex of the cone of dispersion being the mouth of the gorge. In none of these alluvial tracts have any appreciable changes been effected by the storm rainfall of modern times.

Proceeding now to a consideration of the agglomerates, we see that they possess many features that differentiate them from the foregoing beds. They are always found lying either at the foot of fault-terraces or along the lower slopes of other depressed areas. And they are either submerged or lie immediately at the water-line. In no instance have any of them been found in the plateaux. They are very similar in composition and arrangement in every part of the islands. The materials are of local origin, and consist of rounded and subangular boulders, pebbles, and grit. Land-shells are abundant, and at Benhisa and Malak numerous remains of *Elephas Falconeri*, *E. Mnaidra*, and *Hippopotamus Pentlandi* were found. At Dueira and Tal Asiri the bones and horn-cores of *Cervus* sp.? were abundant, and at Hamrun the teeth and bones of *Hippopotamus Pentlandi* were very numerous.

IV.—The Altered Clastic Rocks of the Southern Highlands, their Structure and Succession.

By Peter Macnair.

(*Continued from the April Number, page* 174.)

VIII. The Upper Arenaceous Zone.

I HAVE not been able to trace the exact relationships of this zone, with its bands of limestone, to those already given, as underlying it. Certain grits and quartzites occurring on the top of the Ben Lawers ridge may possibly belong to it, and it is certain that many of the quartzites and grits of Glenlyon, Blair Athole, and Ben Y Ghloe belong to a horizon higher than the upper argillaceous series just described. Leaving the matter thus in the meantime, until further research shall explain their true relationship, it is certain that an arenaceous band of grits and quartzites succeeds the sericite and graphite schists of the upper argillaceous zone, thus completing the whole cycle of deposits, though no evidence has yet been forthcoming to show what or where the top of this series may be.

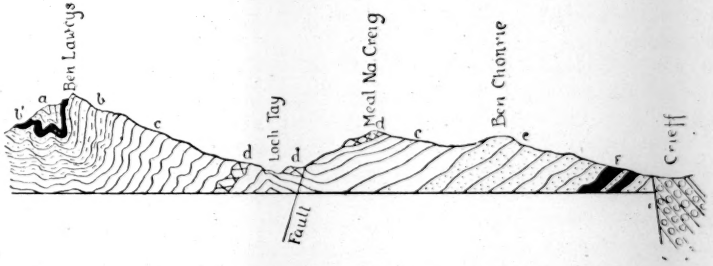


Fig. 1.—Section across Ben Lawers to Crieff.

a. Upper Arenaceous Zone.
b. Upper Argillaceous Zone.
b'. Band of Graphite Schist.
c. Middle Arenaceous Zone.
d. Loch Tay Limestone Zone.
e. Lower Arenaceous Zone.
f. Lower Argillaceous Zone.

IX. Section across Ben Lawers to Crieff.

Passing now to a consideration of these sections seen in Highland Perthshire, from which we have principally been enabled to determine the general succession and character of the rocks forming the Southern Highlands, the first section we propose to describe is that from the top of Ben Lawers, across Loch Tay, through Meal Na Creig, and down Glen Turret, as given above. This section shows in descending order the whole of the zones described. On the north-west side of Ben Lawers, and beside the footpath which leads over from Loch Tay to Glenlyon, a quarry has been opened in the graphitic schist beds that form the uppermost member of our upper argillaceous zone. The graphitic schist is here highly carbonaceous and finely foliated, having evidently undergone an extreme amount of alteration, and lying at high angles, with a dip towards the north-west. This bed is shown in the section at the top of the

upper argillaceous series marked *b*. In the section accompanying his map of Scotland, Sir A. Geikie shows the upper arenaceous series as also being seen on the sharp folds of the upper Ben Lawers strata, but this I have not been able to satisfactorily determine. Passing now to the south-east over the crest of the mountain, we come upon the sericite schist with its bands of quartzite, the lower member of our upper argillaceous series. This rock I have already described. It forms the whole of the top of Ben Lawers, where some very fine sections showing its extreme corrugation may be seen, the precipice on the south-west front being specially worthy of notice. It will be seen from the section that the whole of these beds dip to the north-west at greatly varying angles. Proceeding down the south side of the hill, this rock may be traced for a considerable distance, when it passes into the mica-schists and quartz-schists of the middle arenaceous group. At its base, and intercalated amongst the latter rocks, we come upon the Loch Tay limestone zone, which passes underneath the mountain with a north-west dip. Traced eastwards, it is seen to be cut off by a powerful fault at Fernan; and westwards it is found to enter Glen Dochert at Killin. The limestone here is similar to what we have already described, the two principal kinds being the pure limestone and its argillaceous or micaceous variety. Crossing the loch, the bottom of the latter is seen to be formed by the members of the middle arenaceous zone, underlying the Loch Tay limestone. On crossing to the south side of the loch, the structure and succession of the rocks is here made somewhat complex by the presence of the powerful fault already mentioned, which has been carefully traced by the officers of the Geological Survey. The fault enters the loch to the east of Ardeonaig, crossing and emerging again on the north side at Fernan. In the Ardeonaig limestone quarry, near Dall, the limestone is again met with at a slight level above the loch. This is shown on the section immediately to the north of the fault. From this point the limestone runs westwards to the head of Glen Ogle, and southwards down Glen Beich towards Loch Earn. The downthrow side of the fault is to the north-west, so that in following the section further south, an outlier of the Loch Tay limestone zone is met with on Meal Na Creig. Capping that mountain, and occupying the position as shown on the section, passing over the crest of the mountain and descending its southern side, we again cross the lower members of the middle arenaceous zone, with their characteristic mica and quartz schists. Still further to the south of the section, the latter rocks are seen to merge downwards in Glen Turret into the pebbly grits, greywackes, and quartzites of the lower arenaceous zone, which in turn are succeeded by a narrow band of clay-slates belonging to the lower argillaceous zone.

X. Section across Craig Na Challeich to Loch Earn.

Passing now to another section, about eight miles to the west of that already given, and extending from Craig Na Challeich above Killin to the south side of Loch Earn, we find in it a similar

succession, though somewhat different in structure from that in the Ben Lawers section. The sericite schist of the upper argillaceous zone is the highest bed seen on this mountain, being very well exposed in the bold escarpment of rock forming its summit. This section of the upper argillaceous series is an exceedingly interesting one: besides being well seen in the escarpment of the hill, it is also finely exposed in the beds of two streams that descend from the broken ridge of the corrie. From the summit, which is 2,999 feet above sea-level, down to about the 2,000 ft. contour-line, the mountain is almost entirely composed of a great series of beds of finely foliated sericite schist with intercalated beds of quartzite and greywacke. The sericite schist of this zone I have already described; the quartzites and greywackes may be further noticed.

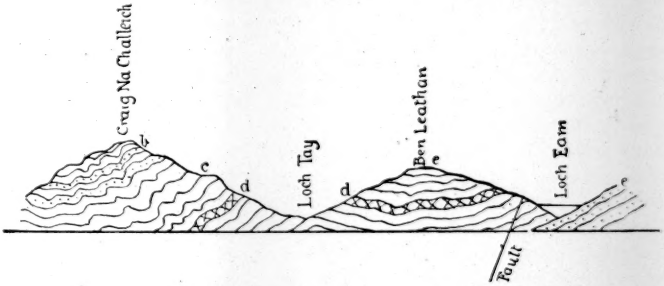


FIG. 2.—Section across Craig Na Challeich to Loch Earn.

b. Upper Argillaceous Zone.
c. Middle Arenaceous Zone.
d. Loch Tay Limestone Zone.
e. Lower Arenaceous Zone.

The quartzites are of an exceedingly fine texture, having been highly indurated, and are plentifully charged with iron pyrites. The greywackes are also of an exceedingly fine character, and show some beautiful examples of lamination. The usual colour is a dark greyish hue, the laminæ or banding being of a lighter shade of the same colour. It is in these bands of greywackes the author found traces of annelid tubes already cited. These annelid tubes have undoubtedly originally been of the ordinary type, being simply cylindrical tubes of sand differentiated out from the surrounding matrix, and passed through the body of the worm. But now, owing to the shearing and metamorphism of the rock, they have been deformed into ovates, the substance of which is generally lighter in colour than the surrounding rock. On weathered surfaces these ovates present all the characteristics of the annelid tubes of the north-west of Sutherlandshire, at times the material composing the ovates being weathered out, and showing on the surface of the beds a series of cylindrical holes similar in every respect to the mouth of an unaltered burrow; at other times, the matter composing the ovate being of a harder texture than the surrounding rock, they stand up in buttons like the nails in a workman's boot. Seen in section these burrows have all been more or less deformed from their original cylindrical form, the whole of them having been

drawn out into ovates, and in the case of extreme shearing have been reduced to a mere line or streak. Seen under the microscope, these greywackes present a finely fragmental structure with occasional crystals of felspar disseminated through the mass. Passing down the mountain-side, we cross the middle arenaceous group, which as usual is composed of massive beds of quartz-schist, often becoming highly garnetiferous. Near the level of the road which passes along the north side of Loch Tay, we come upon the Loch Tay limestone zone, with its massive beds of limestone and calcareous mica-schist; followed eastwards it is found to pass under the base of the Ben Lawers group; westwards it skirts the base of Sron Clachan in a bold escarpment, and thence stretches to the west through Glen Dochert. The sill of altered basic rocks upon which the limestone rests may be well seen on the road leading to Killin Pier. Here the limestone is shown resting immediately upon the sheared basic rock, and evidence of the extreme alteration of the limestone is to be found in the hardened bands of that rock found running along the lines of contact. It is not our intention here, however, to enter into a detailed description of these associated igneous rocks, but merely to mention their occurrence in connection with the clastic series.

Following the line of section and crossing the head of Loch Tay, the lower members of the middle arenaceous group are exposed, lying below the limestone zone, and folded over in an anticlinal axis. They are well seen at the falls of Dochert near the head of the village of Killin, where they are still found dipping to the north-west. Passing up the burn at the back of Auchmore House, the quartz-schists are found to become flatter and flatter till they roll over and dip to the south-east. Near the base of Ben Leathan and at the head of the burn, we again come upon the Loch Tay limestone zone, now dipping to the south-east at a very gentle angle, and capped to the top of Ben Leathan with the upper members of the middle arenaceous group. A transverse section of the latter mountain is well exposed in the deep pass of Glen Ogle; all the beds seen on the higher sides of that glen to the top of Ben Leathan belong to the upper members of the middle arenaceous zone, and are mainly, as usual, composed of massive beds of quartz-schists, with occasional bands of grit and conglomerate. From the head of the Auchmore burn to the old Killin junction at the head of Glen Ogle, the Loch Tay limestone skirts the base of Ben Leathan; down Glen Ogle the quartz-schists and limestone are seen to undulate gently to the south-east, the latter being well exposed in the quarry at Dalveich on the northern shore of Loch Earn. In Glen Ogle several very fine sections of the limestone resting upon the sheared basic rocks are to be seen; one, in particular, about a quarter of a mile north of the Glen Ogle toll-house, exhibits all the phenomena before described as seen on Loch Tay at Killin Pier. On the south side of Loch Earn, the massive beds of grit and conglomerate belonging to the lower arenaceous group are well seen on the sides of Ben Vorlich, where our section is supposed to terminate.

XI. Section across the Pass of Leny.

The next section we propose to describe is one through the Pass of Leny to the north of Callander, which is a particularly favourable one for the study of the lower argillaceous and lower arenaceous zones. The lowest rock seen in this section is our lower argillaceous zone, which runs up immediately to the north of the Old Red

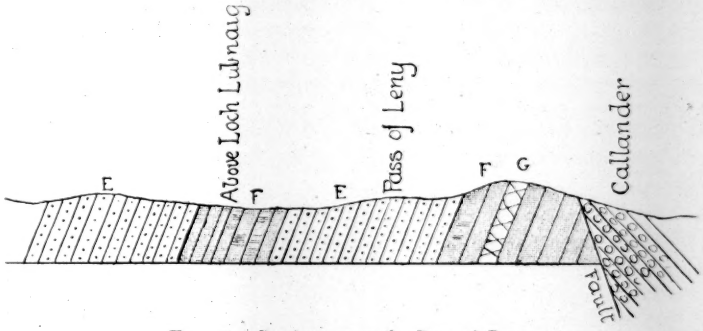


Fig. 3.—Section across the Pass of Leny.
e. Lower Arenaceous Zone.
f. Lower Argillaceous Zone.
g. Leny Limestone.

Sandstone with an average dip of about 50° to the north-west. It is mainly composed of fine greywackes, with beds of clay-slates, and black graphitic schists, and is well seen in the lower gorge of the Pass of Leny, both in the bed of the river and in cuttings along the road. One of the most interesting sections of this series is to be seen in the old limestone quarry. On the hills above the old Kilmahog toll-house here, the limestone is exposed dipping to the north-west at an angle of 50°; the limestone is underlain by a series of beds of black graphitic shales, while above it appears another series of reddish slates, intruded into which we find a vein of quartz felsite strings, and smaller beds of limestone are seen disseminated through the slates. Upon the whole, these lower argillaceous beds remind us wonderfully of the upper argillaceous series found on the Ben Lawers and Craig Na Challeich ridge. The component rocks are exactly the same in both. We find limestones, graphite slates, and such fine argillaceous rocks as clay-slates and greywackes. The rocks of the upper zone, as before observed, show evidence of more extreme metamorphism than the lower, this probably being accounted for by their higher position in the mountain mass, they being consequently more liable to contortion and shearing than the lower members, which would be simply pressed out or indurated. The evidence on this point is not, however, very strong, and will require further and more detailed investigation. Passing from the lower and more argillaceous beds, and further north on the line of section, the latter are seen to pass upwards into a more arenaceous group marked by massive beds of grit, greywacke, and conglomerate.

These are well exposed in the upper gorge of the Pass of Leny, and at the foot of Loch Lubnaig. At the upper part of the Pass, and near the foot of Loch Lubnaig, the greywackes become highly gritty and conglomeratic, the pebbles being composed of quartz and felspar set in a matrix of fine argillaceous material. Along the eastern shores of Loch Lubnaig these greywackes are followed by zones of slates, approaching more closely to a phyllite than any we have seen in this group. They are well exposed in the quarries on the side of the hill, and are shown still dipping, with an average dip of about 50° to the north-west. Passing northwards, they are seen to plunge under the massive beds of grit and conglomerate shown on the south side of Loch Earn and in Ben Vorlich, the position of which to the middle arenaceous zone is shown in the section from Craig Na Challeich to Loch Earn (Fig. 2).

XII. Conclusion.

It now remains for us, in conclusion, to make some general remarks upon the structure, succession, and age of these rocks along the margin of the Highlands. The sections we have described from Perthshire have their beds dipping at such low and gentle angles that little doubt can exist as to their exhibiting the true succession of the beds. Sir A. Geikie notes this fact thus: "Over many square miles the angles of inclination are low, and the successive bands may be traced from hill to hill across strath and glen, forming escarpments along the slopes and outliers on the summits precisely as gently undulating beds of sandstone and limestone may be seen to do in the dales of Yorkshire."[1] In Perthshire and to the north-east, in the counties of Forfar and Kincardine, along the Highland border, the order of succession we have just given seems to hold good so far as we have had opportunities of observing; while on the other hand, to the south-west of Perthshire and in the counties of Argyll and Dumbarton, the rocks of the southern margin of the Highlands have been plicated into a deep and acute synclinal fold with a reversal of dip; this reversal being well shown in the Ben Lomond section, where from the clay-slates on the margin of the Highlands, and inward towards Ben Lomond, the whole series of grits, slates, and greywackes are seen to dip to the south-east. Thus our conclusion as to the true succession of these rocks is exactly the opposite to that arrived at by Prof. Nicol.

Turning now to the difficult subject as to the age of these rocks, little can yet be said as regards their true position in the geological scale. The discovery of radiolarian cherts associated with the graphitic schists of our upper argillaceous zone, according to Sir A. Geikie, seems to point to the identity of these higher rocks with the Ordovician of the southern uplands; while our annelid tubes occurring near the base of that zone might point to the similarity of it to the Cambrian quartzites of the north-west of Sutherlandshire—thus

[1] Quart. Journ. Geol. Soc., Presidential Address, vol. xlvii, p. 73.

making these upper rocks represent a succession from Cambrian through a Lower Silurian series, while the lower members represent a still older group of rocks, some of which may be the deep-sea equivalents of the pre-Cambrian conglomerates of Loch Torridon and other parts of the west coast, an idea which I pointed out some years ago.

TABLE OF THE ALTERED CLASTIC ROCKS OF THE SOUTHERN HIGHLANDS OF SCOTLAND.

ZONE.	ROCKS.	LOCALITIES.
Upper Arenaceous Zone.	Limestones. Quartzites.	Glen Tilt, Blair Athole. Glenlyon, Schiehallion, Ben Y Ghloe.
Upper Argillaceous Zone.	Graphite Schist. Sericite Schist. Quartzites and Greywackes, with Annelid Tubes.	Ben Lawers, Glenshee. Loch Fyne, Ridge north of Loch Tay. Craig Na Challeich, Ben Lawers, Killin.
Middle Arenaceous Zone.	Garnetiferous Quartz-schists and Mica-schists, with bands of Grit and Conglomerate.	Loch Tay, Loch Earn, Glen Dochert, Balquhidder.
Loch Tay Limestone Zone.	Pure Limestone and Micaceous Limestone.	Loch Tay, Loch Earn, Glen Dochert, Ashintully.
Middle Arenaceous Zone.	Garnetiferous Quartz-schists and Mica-schists, with bands of Grit and Conglomerate.	Loch Tay, Loch Earn, Glen Dochert, Balquhidder.
Lower Arenaceous Zone.	Massive Grits and Conglomerates. Grits, Greywackes, and Quartzites.	Ben Ledi, Ben Vorlich. Pass of Leny, Glen Leadnock, Forneth.
Lower Argillaceous Zone.	Clay-slates and Phyllites. Limestone. Graphite Shale, Red and Purple Shale.	Aberfoil, Loch Lubnaig, Pass of Leny. Kilmahog, Pass of Leny. Kilmahog, Pass of Leny.

V.—PALÆONTOLOGICAL CONSIDERATIONS ON THE OLD RED SANDSTONE OF SCOTLAND.

By PETER MACNAIR and JAMES REID.

The Ganoidian Fishes of the Old Red Sandstone.

HOWEVER paradoxical it may appear, we have reason to believe that the occurrence of so-called ganoidian fishes—of a fresh-water type—in the Old Red Sandstone affords the strongest evidence in favour of its marine origin. That recent representatives of the ganoids of the Old Red Sandstone inhabit rivers and lakes of the

globe, is by no means a proof of the fresh-water origin of the latter fishes. The immense interval of time implied by the comparison renders its value somewhat problematical. Sir A. Geikie, in referring to the fishes of the Old Red Sandstone, says: "That some of the fishes found their way to the sea, as our modern salmon does, is indicated by the occasional occurrence of their remains among those of the truly marine fauna of the Devonian rocks." [1]

The life history, however, of the salmon presents evidence of a somewhat different kind; for we find that the Salmonidæ made their appearance for the first time in the *Chalk* of the Cretaceous system,[2] which would rather indicate a migration *from* the sea. In like manner, the life history of these obscure representatives of the ganoids of the Old Red Sandstone would probably show that they preserved their existence "in the struggle for life" by a successful adaptation to new surroundings—namely, fresh-water conditions—while their less-favoured contemporaries succumbed.

The large numbers of fish-remains entombed in the Caithness flags indicate a widespread and sudden destruction of life. Earthquake shocks, the discharge of mephitic gases, and heated waters have been respectively suggested as the cause of the catastrophe. But whatever the agent of destruction may have been, it apparently came in from an outside area, sweeping before it the fishes of the Old Red Sandstone of Caithness inward towards the shallow shores, where they perished. In referring to the flagstone quarry of Achanarras and its contained fish-remains, Dr. R. H. Traquair states that in the lower bed, two and a half feet in thickness, "there all the species in the list occur almost indiscriminately." [3] It is impossible to conceive the manner in which dead fishes could be preserved entire, during the formation of sandstones and shales of several feet in thickness, in a *tideless fresh-water lake.* But a shallow seashore, presenting broad stretches of sandbanks and mud-flats, would afford a more adequate medium for this purpose. The diurnal tides, on the one hand, laden with sand and mud in their ebb and flow, would undoubtedly cover up immense numbers of the fishes in question; while, on the other, the antiseptic properties of salt water would tend to their preservation, even for some time afterwards.[4]

The Introduction and Geographical Distribution of the Old Red Sandstone Fishes.

With regard to the introduction and geographical distribution of the fishes of the Old Red Sandstone, the case of the "Lake theory" displays conspicuous weakness. The Eurypterids and Cephalaspidians of the Upper Silurian are in evidence; but of the genera *Osteolepis, Dipterus, Glyptolepis,* and other fishes of the Old Red Sandstone, no undoubted plates or scales occur in the preceding formation. The question therefore arises, whence came these highly organized

[1] "Classbook of Geology," 1890, p. 262.
[2] Günther, "Study of Fishes," 1880, p. 631.
[3] Proc. Roy. Phys. Soc. Edinburgh, vol. xii, p. 283.
[4] Proc. Perthshire Soc. Nat. Sci. 1893–4.

fishes of the Old Red Sandstone? More especially, from what fresh-water region did they migrate? Not only so, but as the same genera of fishes occur in the Devonian of North America and the St. Lawrence basin, we have an equal right to know by what fresh-water pathway of distribution they were enabled to migrate some 3000 miles between one point and another.[1]

But so far as these questions are concerned, the advocates of the "Lake theory" have maintained an ominous silence. Some eminent palæobotanists have advocated the view of an Arctic origin and southward migration of the flora of the globe; while Dr. A. Wallace also believes "in the northern origin of both the fauna and the flora of the world."[2] The simultaneous occurrence of ganoidian fishes of the same genera and species in the formations of North America and Britain, and in the Devonian of Russia and Central Europe, seems also to indicate a boreal origin and southward migration of the fishes of the Old Red Sandstone. In this connection the genus *Acanthaspis* (Newberry), of the Devonian of Ohio, is of especial interest. A specimen of this fish from the Lower Devonian of Spitzbergen is figured and described by Mr. Smith Woodward,[3] while Dr. R. H. Traquair mentions its occurrence in the Lower Devonian of Prüm in the Eifel.[4] These discoveries thus show an extremely wide range for this Placoderm of the Devonian.

Stratigraphical and Biological Comparisons.

We find Sir A. Geikie stating that no unequivocally marine fossil remains occur in the Old Red Sandstone.[5] We believe we are correct in assuming that our author refers to the fishes and crustaceans alike as equivocally marine remains. We have, however, seen no reason assigned why Eurypterids and Placoderms of the same genera, which are marine in the later Upper Silurian, and fishes of the same genera and species, which are equally marine in the Devonian of Russia and Central Europe, as well as in the Devonian of North America, should be termed equivocally marine in the Old Red Sandstone. But further, Sir A. Geikie refers to the occurrence, in the heart of the Old Red Sandstone of Lanarkshire, of a band of rock about 5000 feet above the base of the system, containing true Silurian fossil remains, whose occurrence he attributes to an irruption of an outside sea of Silurian character.[6]

The Evidence derived from Fossil Plant-Remains.

It has been frequently assumed that the presence of land plants in the Old Red Sandstone is a proof of its fresh-water origin. But from an *a priori* point of view, no good reason can be assigned against the occurrence of land plants in either the sea, on the one hand, or in inland lakes, on the other. As a matter of fact, plant-remains occur indifferently in the Old Red Sandstone and Devonian.

[1] Proc. Perthshire Soc. Nat. Sci. 1893–4.
[2] Brit. Assoc. Address by Sir J. D. Hooker, 1881.
[3] Nat. Science, vol. i, No. 8, p. 602.
[4] Ann. and Mag. Nat. Hist., sec. 6, vol. xiv, p. 370.
[5] "Textbook of Geology," 1882, p. 706.
[6] *Ibid.*, p. 714.

Land plants of the same genera and species are met with in the Old Red Sandstone and Devonian of Europe and North America. In littoral deposits they occur abundantly, but in deep-water deposits they are more sparingly met with. On the other hand, traces of seaweeds undoubtedly occur in the Old Red Sandstone. In the sandstones of Gaspé, *Nematophyton* (with which *Pachytheca* is closely associated) is prevalent. This plant has been referred by Penhallow and Carruthers to the Algæ. *Pachytheca* is met with in the sandstones of Murthly[1] and in the flags of Forfarshire, while in a late edition of Page's Geology an undoubted fucoid is figured from the Old Red Sandstone of Roxburghshire. Nicholson also says: "The Old Red Sandstone of Scotland contains a good many fragments supposed to belong to seaweeds."[2]

The Key to the Devonian Question.

Perhaps in the Middle Devonian of the Russian formation we find the strongest evidence in favour of the marine origin of the Old Red Sandstone. From the northern to the southern boundary of Russia the Devonian deposits have remained comparatively undisturbed to the present day. In the Russian formation "the Devonian and Old Red Sandstone types appear to be united, the limestones and marine organisms of the one being interstratified with the fish-bearing sandstones and shales of the other."[3] "Indeed, cases occur where in the same band of rock Devonian shells and Old Red Sandstone fishes lie commingled."[4] The lower division of the Devonian being absent in the Russian formation, no crustaceans or cephalaspidian fishes occur; but in the lower part of the system (Middle Devonian) we find the remains of the genera of *Osteolepis*, *Dipterus*, etc., "which are specifically identical with those of the Old Red Sandstone of Scotland."[5] The characteristic *Holoptychius nobilissimus* and *Bothriolepis* and other fishes of the Old Red Sandstone of Scotland are met with in the upper division of the Russian Devonian, as well as in the Devonian of North America. In the fish-bearing sandstones of the Devonian of Russia no marine shells occur. This may be generally said of the red sandstones and shales of the Old Red Sandstone of Britain, though in the Welsh area *Conularia* (whose recent representative is a denizen of the deep sea) is met with. *Orthoceras dimidiatum* and other marine remains occur in the Old Red Sandstone of Lanarkshire. It is in the St. Lawrence basin, however, where marine shells are more numerously met with. Sir Wm. Dawson says of the marine shells of the Nova Scotian beds: "With respect to the fossils, I may remark that they are all marine; that they belong to numerous genera and species."[6] "Some of the fine beds (of Gaspé) hold shells of *Lingula* and *Modiomorpha* of

[1] See *Nature*, 10th April, 1890.
[2] "Manual of Palæontology," 1872, p. 521; also Annals of Botany, vol. v, No. xviii, p. 158.
[3] "Textbook of Geology," A. Geikie, 1882, p. 703.
[4] *Ibid.*, p. 704.
[5] *Ibid.*, p. 704.
[6] "Acadian Geology," 1855, p. 315.

Hall."[1] It is interesting to note that "a large lamellibranch, closely resembling the Irish *Anodonta*,"[2] is met with in the Devonian of New York.

Conclusion.

We freely admit that the geological opinion of the present day is largely in favour of the fresh-water origin of the Old Red Sandstone. The unique character of the strata, the presence of well-defined lake boundaries, and the absence of marine fossil remains have been freely assumed, whilst supporting evidence is conspicuous by its absence. In the Cambrian formation of Wales we find large zones of red sandstones and conglomerates, rivalling, if not exceeding, in extent similar deposits which characterize the Old Red Sandstone of Scotland. The so-called boundaries of lake basins of the Old Red Sandstone would be somewhat difficult to find, for (if we may use the term) they appear to be "of a one-sided order." In the Welsh area, the South of Ireland, and the North of Scotland, the Old Red Sandstone runs out to sea; while in Midland Scotland, if the Old Red Sandstone thrown down by the great fault which stretches across the country from Ayrshire to Midlothian were raised to its original position it would show a south-eastward trend, towering some 12,000 feet over the highest peak of the Southern Uplands.

The marine denudation of the Silurian rocks of the Highlands of Scotland is not in dispute, but Ramsay and Geikie have assumed a subsequent lake or fresh-water denudation. The conformable deposition, however, of the Old Red Sandstone upon the preceding Upper Silurian deposits in the counties of Edinburgh and Lanark, the Welsh area, and in the St. Lawrence basin, precludes any such idea; for from the base of the Upper Silurian to the top of the Lower Old Red Sandstone the sequence of these deposits is unbroken. It therefore follows that the denudation of the rocks of the Highland area being marine, the equivalent deposits occurring in the Upper Silurian and Lower Old Red Sandstone are equally marine. We find in the Moray Firth area a large stratum of yellow *saliferous* sandstone, interbedded with shales containing remains of Old Red Sandstone fishes.[3] This stratum of *saliferous* sandstone is well exposed in the precipice of the Burn of Eathie, near Cromarty, and we think but one conclusion alone can be drawn therefrom—that the formation and its contained fish-remains were marine. The widespread occurrence of so-called fresh-water fishes in the Devonian of Russia, Central Europe, Britain, and North America, renders the "Lake theory" view of the fresh-water origin of these fishes utterly untenable. Finally, we feel justified upon both physical and palæontological grounds in concluding that the Old Red Sandstone and Devonian, in their respective littoral, shallow-water, and deep-sea deposits, represent the one Devonian system, *which is marine.*

[1] Report Geol. Surv. Canada, 1871, p. 4.
[2] "Textbook of Geology," A. Geikie, 1882, p. 706.
[3] "The Old Red Sandstone," 4th ed., 1850, p. 285.

VI.—On the Old Red Sandstone and Carboniferous Rocks of the North-east of the Island of Arran.

By James Neilson,
Vice-President of the Glasgow Geological Society.

(*Continued from the April Number*, p. 161.)

In the Transactions of the Edinburgh Geological Society (vol. v, p. 316) will be found a notice of a section at Lochrim Burn, a quarter of a mile south of Corrie, where is exposed a bed of red sandy shale containing marine fossils. The catalogue contains fifteen species (certified by Mr. John Young, LL.D.), and every one of these is common in the Carboniferous Limestone series of the West of Scotland. This bed is overlain by another bed containing abundant plant-remains, of which a list of seven species is given. The Rev. D. Landsborough, of Kilmarnock, found here another, viz. *Carpolithes sulcatus*, L. and H. ("Fossil Flora," pl. ccxx), which Mr. Kidston considers to be characteristic of the Calciferous Sandstone series. It seems to me, however, that the evidence is rather in favour of these beds belonging to the Limestone series. Then, as already noted, there are the fireclays, of which I have observed several distinct beds along the Corrie shore. There is also a bed of fireclay in the old quarry behind Corrie Hotel (within 100 feet of the *Productus giganteus* limestone); this overlies a bed of fine white sandstone. Fireclays also occur in the gap between the northern and the great eastern cliff.

So far as I am aware, fireclays have not hitherto been recorded from Arran, but they have an important bearing on the question presently at issue. Let us again quote Geikie (pp. 806–814): "Fireclay or shale, through which rootlets branch freely in all directions. . . . . They appear to be the soil in which the coal grew."

These Arran fireclays differ in no respect, except that some of them are redder or whiter than those I am so familiar with near Glasgow, being crowded with rootlets, while here and there the usual *Stigmaria ficoides* is to be seen. Some of these fireclays show the peculiar slicken-sides so well known.

These Red Sandstone strata not only contain fireclays, but also ironstone, which occurs as nodules (in the fireclays and shales) varying in size from half that of pin-heads upwards to about a foot in greatest diameter. There are also regular bands of ironstone, which may be seen at Corrie, both on the shore and in the old quarries already referred to, and also on Maoldon and the mill burn at Brodick. The ironstone is nearly all in the state of peroxide (hematite iron ore), which is doubtless the colouring material of all the red rocks of Arran; in fact, we have concluded that the nodules and possibly the seams of hematite are simply segregated out from the abundance of this material: one very striking instance being that of a nodular band about one inch thick

which has apparently entirely exhausted the red matter from the clay in which it lies, leaving the clay of a creamy white colour.

Returning now to the question of marine limestones—If they belonged to the Old Red Sandstone age, one would have expected the fauna to be of Devonian rather than of Carboniferous type; and it would indeed be strange if there should exist at the same time in the sea, in what is now Devonshire and Arran, two faunas so dissimilar as are the Devonian and Carboniferous, and that changes should occur involving the annihilation of the entire Old Red Sandstone and Devonian fauna, and yet leave these Carboniferous fossils unchanged throughout all the long period represented by the Upper members of the Old Red Sandstone,[1] and the whole of the Calciferous Sandstone period to be again introduced unaltered into the British area at the beginning of the Carboniferous Limestone period. It may be so, but I cannot accept it without proof. On the contrary, the fossils show undoubtedly that these are the true Carboniferous Limestone strata themselves. Dr. Bryce (p. 224) records some 36 species of marine fossils from these beds, all of which are found elsewhere in the Carboniferous series of the West of Scotland. The thing that strikes one most in the limestones at Corrie, Laggan, and Maoldon, is the enormous number of *Productus giganteus* to be seen.[2]

Now, it will be generally conceded that species, like individuals, have first a period of infancy, and then a full development, from which they dwindle and gradually die. *Productus giganteus* is no exception to this rule, and its period of overwhelming development is well known in the West of Scotland near the bottom of the Limestone series, where some of the beds are known as *Productus giganteus* limestone.

This series of beds is the thickest of the lowest limestones, and is generally called the main limestone; they have been extensively worked at Beith, Dalry, Busby, Hurlet, Campsie, Carluke, etc., and I have no hesitation in setting down the Corrie limestones as the equivalents of this series of beds, to whose position they correspond stratigraphically. It was my intention to re-examine the shore south of Brodick Bay, in order to have worked out the evidence in that direction, but the broken state of the weather prevented me from completing this part. I may, however, say that the evidence here is not so complete, nor so continuous; while the greater part, if not the whole, of the strata between those already described and the

[1] [The author should bear in mind that many authorities are inclined to group Upper Old Red Sandstone in the Carboniferous system. The "Upper Old Red" of North Wales and the so-called "Old Red" of the Lake District are now grouped as Basement Carboniferous. The uppermost Devonian beds have a Carboniferous fauna. With regard to the Arran limestones, however, Sir A. Geikie has himself corrected the error. See sequel to this paper, p. 227.—Edit. Geol. Mag.]

[2] I measured a square yard in the roof of one of the mines, and counted in it 48 shells of this species. I also counted in the face of the quarry 21 layers of these shells. These figures show that each layer contained (48 × 4840) over 232,000 shells per acre, and this, multiplied by the number of layers, gives nearly 5,000,000 shells per acre; a number which, however gigantic, is, I am persuaded, under rather than over the actual fact.

thick sandstones which overlie the upper limestones near the Cock o Arran, appears to be wanting.

I will, therefore, take up the strata on the north coast, at the poin half a mile north of the shepherd's house at Laggan. This part i generally called Salt Pans. These consist of sandstones and shales with two or three seams of coal, which have been wrought down t the level of the sea; also several ironstones, three bands of which exposed in a little bay, have long been noted for their beautifully tessellated structure.[1]

No marine remains have been recorded, nor observed by me from these strata, the beds presenting the appearance of having been de posited in fresh water. They contain numerous plant-remains, mostly indecipherable, although *Stigmaria* is common, and I found a smal frond of *Sphenopteris*. Dr. Bryce says (p. 128) that "the shale and coal tract is bounded by a black limestone below and a red limestone above, 1400 yards apart." These lie between the Lower and the Upper Limestone series, and I believe they are the representatives of what are denominated in the West of Scotland "the Middle Coal and Ironstone series." These are represented in the neighbourhood of Glasgow by the Possil and Govan Coals and Ironstones, with which they correspond in geological position, mineral character, and economic products of coal and ironstone, although we have not observed the *Lingula*, which is so characteristic of this division.

Proceeding still north-west along the shore, we find overlying the last group another series of red rocks, even redder than before. These consist of sandstones, shales, and several limestones. The limestones are charged with marine fossils; one bed (the lowest) being covered with shells of *Productus latissimus*,[2] while another abounds with large stems of encrinites, and a third with various shells. Not only these beds, but the fossils they contain are as red as any Old Red Sandstone rock in Scotland. These beds exhibit a decided change from the last group, viz. a change from fresh-water to marine conditions.

I consider these beds to belong to the Upper Limestone series, to which they correspond in stratigraphical position. *Productus latissimus* attains its greatest development at a certain horizon known in the West of Scotland as the *Productus latissimus* limestone, also as the Index or Cowglen limestone, which is the lowest limestone in the Upper Limestone series; and I am inclined to consider the Arran bed charged with *Productus latissimus* to be the Index Limestone itself.

Overlying these rocks at the Cock of Arran are thick beds of sandstone, then breccias, then sandstones again, till the whole are cut off by a great fault and by the slates coming down to the shore. It will be observed that these sandstones occupy the natural position of the Millstone Grit, and as no unconformity or break in the

[1] This bed is referred to by Mr. E. A. Wünsch in a paper, "On a Coast Section at Arran," read before the Geological Society of Glasgow, March 2nd, 1871: Geol. Mag. 1871, Vol. VIII, p. 226.

[2] See Mr. E. A. Wünsch's paper already referred to.

sequence has been recorded or observed, I am inclined to relegate them to that position. These sandstones, etc., were described by Sedgwick, Murchison, and Ramsay, as belonging to the New Red Sandstone formation, while Bryce sets them down as belonging to the Upper Carboniferous series (we presume the equivalents of the Bothwell red sandstones, which overlie the highest of the Lanarkshire coal-seams).

In Sir Archibald Geikie's Geological Map of Scotland, published 1892, these rocks are set down as Upper Old Red Sandstone; but they clearly overlie, probably, one thousand fathoms of strata containing Carboniferous fossils; and, more astonishing still, the pebbles of the breccias in these red sandstones contain fossils of Carboniferous age, originally discovered by Mr. James Thomson, F.G.S., a fact well known to the members of this Society many years ago.

These rocks, then, may be considered as the highest rocks in this part of Arran, and it is evident that the Upper Coal-measures are absent.

I have already stated that the ring of slates or schists completely encircles the granite, but Sir A. Geikie's map shows, on the east, the granite in contact with the Old Red Sandstone for a distance of about three miles. This is not so in the White Water (described in all the Handbooks), nor in the Punch Bowl, or Coich-na-Oich junction, where the granite and slate can be seen in contact. The rocks here are coloured as Lower Old Red Sandstone, while I am inclined to regard them as Upper Old Red Sandstone.

For comparison with the Arran rocks I append Sir Archibald Geikie's Synopsis of the Carboniferous Limestone Series of Scotland.[1]

Carboniferous Limestone Series.	Group of sandstones and shales, with three or more seams of limestone (Castlecary, Calmy or Arden, and *Index limestones*).
	Sandstones, shales, coals, and ironstones, but *with no limestone bands*.
	Sandstones, shales, fireclays, corals, and ironstones, with several thin limestones (Hosie's) towards the top, and the *thick main or Hurlet Limestone* at the bottom.

This, it will be seen, agrees with the Arran section.

And now, in conclusion, I cannot help asking the question—Is there any way of accounting for the redness of the Arran rocks, so different in many cases from their equivalents elsewhere?

The ironstones appear to have been deposited in a manner exactly similar to the Clay-bands of the mainland, and I am strongly of opinion that originally they were similar, and that the alteration to peroxide took place subsequently to their deposition and segregation, and was due to some change which did not apply to the West of Scotland generally.

I am inclined to attribute this change to heat. The red rocks of Arran are situated round, and at no great distance from, a granite nucleus, upheaved to its present position subsequent to the deposition of the stratified rocks, and it is just possible that to the long-continued

[1] Explanatory Notes accompanying a new Geological Map of Scotland. 1892.

and gentle baking, to which they must have been subjected, is due the alteration to red oxide, both in the ironstones and sandstones. That bricks assume their red colour by firing is common knowledge; and, although a heat sufficient to burn a brick might destroy a fossil in the limestone or shale, yet the heat required to effect the change in colour may not be so great after all—as one sees in the case of the lobster that is affected by the heat of boiling water.

I throw out this suggestion with considerable diffidence, knowing it to be open to many and serious objections; but it is the only hypothesis I can suggest, and even should it prove to be erroneous, it may evoke a better and truer solution.

Since the above remarks were penned a curious circumstance has come under my notice, which has a bearing on this point. Some time ago, during excavations for a gas-holder tank at Thornhibank works, the excavated material was carted away and thrown down at Arden old quarry. It proved to be a fossiliferous shale, containing a large number of ironstone nodules. After lying some time it took fire, owing probably to spontaneous combustion, and has been smouldering away for the last month or two. The heat in the deeper parts was probably great, but on the surface was not very high—perhaps from 120° to 150° Fahr.; yet this heat has been sufficient to alter the colour of the ironstone nodules from dark-brown or blackish to red, as shown in specimens obtained by me, some of which contain fossils which have been altered but not destroyed.

Another point is the condition of the fireclay and shales charged with plant-remains. The presence of the carbonized plant-remains turns the shales and fireclays in which they occur, black, and I believe this to be the invariable rule, and feel pretty safe in saying that any which are not black have been subjected to alteration.

The effect of heat is to drive off the carbon and leave the shale white, or, if it contains iron, reddish—a fact familiar to every housewife in the country who buys stones along with her coals. Then there is the fact patent to all, that bricks, whether made from fireclay or dark carbonaceous shales, are white.

Now, none of the shales or fireclays among the red rocks of Arran are black; they are either of a creamy white or reddish colour. That alteration, as we have shown, could have been produced (and I am inclined to think has been produced) by heat.

Proceeding from observation to experiment, I took some specimens of fireclay filled with small ironstone nodules of a dirty black colour (which had been discovered by Mr. J. B. Wyse at Blochaim, north-east of Glasgow) and put a piece into the parlour fire, heaping coals over it. After about two hours roasting it was found that the black colour was gone, the matrix was changed to a white colour, and the ironstone nodules had been altered to a blue colour. As, however, I was under the impression that too much heat had been applied, another specimen was put into the fire before retiring for the night, and in the morning the result was more satisfactory. The matrix was white, and the iron in the condition of red oxide.

It may be explained that these specimens were selected from their resemblance (in all but colour) to a very remarkable and interesting bed found in Maoldon, Arran, and that after the experiments the specimens might very well have been mistaken for Arran ones.

NOTE.—After the reading of the paper on October 17, 1895, the Secretary of the Glasgow Geological Society was requested by Sir A. Geikie to mention the fact that the statement as to the Arran Limestone had already been corrected by him in his Annual Report to the Science and Art Department for 1894, which was sent, soon after publication, to the Mitchell Library, Glasgow, on Sept. 5, 1895.

The author desires to add that he was entirely unaware that Sir A. Geikie had published any statement on the subject, otherwise he would have embodied it in his paper. He now adds the following extract from Sir A. Geikie's Report referred to above :—

"PERMIAN (p. 284).—The age of the red sandstones which extend along the shore from Corrie to Brodick and thence across the southern half of the island, underneath the various sheets of eruptive rocks, has been much discussed.

"By Sedgwick and Murchison these strata were classed as New Red Sandstone, a view which was subsequently adopted also by Ramsay. Afterwards, however, Bryce and other writers placed them in the Carboniferous system and correlated them with the red sandstones of the north of Ayrshire and Renfrewshire. A re-examination of the ground was made by me last spring, in company with Mr. Peach and Mr. Gunn. We found that pebbles of the Carboniferous Limestone and its characteristic fossils actually occur in the breccias at the base of these red sandstones between Corrie and the north end of Arran, as was first observed some years ago by Mr. James Thomson. Closer inspection of the coast-sections and of the interior showed us that, besides this evidence of a decided stratigraphical break, the red sandstone, conglomerates, and breccias lie unconformably on the Carboniferous formations, though at the actual junctions the two series seem almost conformable.

"It was thus manifest that these red sandstones could not be Lower Carboniferous as was supposed, but must be later than the Carboniferous Limestone series. North of Corrie they rest on the uppermost members of the Limestone series or the base of the Millstone Grit. In the interior, at the head of Benlister Glen, they lie on the Corrie Limestone hundreds of feet lower down in the Carboniferous system, while on the west coast, at the mouth of the Machrie Water, they appear to come directly down upon the Old Red Sandstone, the whole of the Carboniferous formations having there disappeared. These upper unconformable, and overlapping red strata may be divided into two fairly well-marked sections—a lower group consisting of massive false-bedded sandstones varying from a bright brick-red colour to tints of yellow or grey; and an upper group of red marls, and shales, containing thin sandstones and occasional thin seams of nodular limestone . . . . . That they are probably Permian, may be inferred . . . . . "

REVIEWS.

I.—Ice-Work. Present and Past. By T. G. Bonney, D.Sc., LL.D., F.R.S., F.S.A., F.G.S., etc. 8vo, pp. 295, with 24 maps and diagrams, and frontispiece from a photograph. (London: Kegan Paul and Co., 1896.)

THE value of hypotheses or of well-considered inferences from known facts must depend, partly, on the personality of the thinker, on his usual habit of thinking and lines of thought; and partly whether the basis of his inferences rests on direct observation or on statements of facts by others. "Gather facts for yourself and then submit them to inductive reasoning," has been Dr. Bonney's advice to students; and certainly he has acted on it himself.

First, he sketches the general and special features of some Alpine regions which offer available evidence of ice-action in various ways, and which he has personally examined (pp. 3–37). Secondly, he reproduces the statements of good observers relative to the Arctic and Antarctic ice-sheets (pp. 38–75). The features and conditions of the Great Aletsch Glacier and its tributaries are described by the author from personal observation. The origin of the ice-river in the fields of dry snow and "frozen snow" of the heights is followed by its slow downward progress, with débris from the mountains, scattered or trailing on its surface. This often falls into the body of the ice by fissures; but chiefly it forms the moraines along the edges, which ultimately unite at junctions, and altogether become exposed at the melting of the glacier. Both perched blocks and great moraines result. The ice itself is allowed to have some abrading power (p. 10). The débris imbedded in its mass aids it; but more especially the blocks, stones, grit, and sand are ground, and grind the rocks at the bottom of the ice; and here also, together with mud, they form a "ground-moraine," which is as variable as the dimensions and conditions of the glacier and its imbedded rock-material. Superficial snow and ice melting in sunshine give water, which furrows the surface until lost in crevasses; and locally waters from the valley-sides plunge beneath the glacier. These all help to augment the ground-moraine, or maintain the chief line of the sub-glacial drainage. Here the pot-holes are made by gurgitation of stones and water, besides the rounded hummocks of the striated, smooth, and more or less polished floor.

Hence, though local appearances, due to other causes, may be mistaken for some of them, such conditions and phenomena as those mentioned above may be taken to indicate the path of a vanished glacier. This, though nowadays a commonplace statement, is offered by the author in a detailed form from personal observation, as a basis for his inductions.

Continuing his observations in the valleys below the ends of the glaciers, although the features vary in some degree from place to place, it is evident that far above the bed of the valley the rocks

are rounded, smoothed, and striated; and perched blocks and scattered débris indicate that the bulk and sides of a glacier reached to these heights. V-shaped valleys, cut and hollowed out by water, have thus been filled with ice, now gone, leaving smooth and often bare surfaces; and their moraines, consisting of rocks other than those of the neighbourhood, tell of their former existence and work. The moraines, however, and the generally turbid stream issuing from below the end of the glacier, represent really the talus from the frost-bitten mountain-sides, and relatively but little material removed from the floor or sides of the glacier. The destructive work of mountain-torrents, though spasmodic, is found to be much more important than that of glaciers (p. 22). Thus, it is found (1) that in glaciers of moderate size, such as those of the Alps, the "ground-moraine" is absolutely small; (2) that the ice may *abrade*, but cannot *excavate*; (3) that its movements resemble those of an imperfect fluid.

The external and internal differences between recent and old moraines are noted; those near Lake Zurich being examples that the ancient and great glaciers of the Alps advanced and retreated, probably more than once, during the prevalence of an extensive ice-sheet, which reached down over almost the whole of the Swiss low-land, and rose up against the Jura for 3000 feet above Neuchatel lake, and extended northwards to near Soleure. This is indicated on a sketch-map of the glacial movements in France, Switzerland, and part of Germany. The ancient Rhône Glacier had an estimated length of at least 245 miles.

The glaciers on the southern side of the Alps are the dwindled representatives of gigantic predecessors, which, scarcely less extensive than those on the northern side, descended in the old valleys, passed over the sites of the Italian lakes, on to the plains of Piedmont and Lombardy, as shown by their moraines.

Land-ice has left its marks on the Alpine region, but in Greenland it is still in possession, representing a Glacial Period there. Records of the temperature and precipitation in Greenland, its configuration, ice-field, and glaciers, are then dealt with. Having collected the evidences of ice-action and its results in Switzerland and Greenland, Dr. Bonney proceeds to a still wider view of glacial phenomena.

With regard to Arctic and Antarctic ice-sheets, the facts collected by explorers, and summarized by the author, give him such a general idea of the conditions prevailing, and the processes at work during a Glacial Epoch, as follows:—(1) There must have been a mean annual temperature not exceeding 32° F. (2) A fair amount of precipitation, chiefly as snow. (3) An expanse of hilly upland; huge rolling fells being more favourable than lofty peaks and deep valleys; the latter would be a region of gigantic glaciers, becoming confluent outside the hill-region. (4) A general gradual slope, for the extension of the ice. (5) Proximity of the sea, although favouring precipitation, would restrict the advance of the ice.

There is heavier precipitation on the Antarctic coasts, and steeper and more uniform surface-slopes; hence their valley-glaciers are far

greater than those of Greenland, and every slope becomes an ice-field moving outwards and downwards to the bed of the sea (p. 68).

The Alaska glaciers furnish many interesting facts. At the end of the great Malaspina glacier portions of the old submarine morainic material (at least 4000 feet thick) have been faulted up along eight to ten miles into hills at least 3000 feet high, within the recent period. Part of the glacier is covered by moraine with forests. The glacier itself is seen, in natural sections, to lie on unconsolidated gravel and clay; and the surface-waters, forming tunnels in the ice, carry much coarse débris into the subglacial drainage, and help to form ridges of gravel and sand not unlike "kames" and "eskers" (p. 74).

The relation of glaciers to "lake-basins" is then taken in hand (pp. 79–94). An *abrading*, but not any appreciable *excavating*, power is allowed to glaciers. Although the occurrence of lake-basins frequently coincides with glaciated regions, yet many such lakes occur where no glaciers have been, and none occur at some places which glaciers have traversed; and "the direct evidence generally is adverse to the excavatory action of ice, except under very special circumstances." Differential earth-movements are real causes for such sunken basins.

The origin of the "Parallel Roads of Glen Roy" coming within the range of glacial possibilities, is here discussed (pp. 94–107), after a brief description, with a careful exposition of views hitherto held —chiefly those advanced by Jamieson and Prestwich. The objections to a marine origin for these "roads" are regarded as insuperable. It is difficult to account for a local glacier huge and solid enough to dam up so large a sheet of fresh water as would be required to form these marginal terraces, at the time when Glen Roy itself and parts of neighbouring valleys were free from ice; so the subject is left open for further elucidation.

The origin of the isolated mounds of gravel and sand known as "kames" and "eskers" is also found to be too difficult for definite explanation, even by one so experienced in ice as the author. He gives the views of several writers; and, indicating the weak points, he cautiously concludes that, possibly, if these ridges be the leavings of ice-sheets, the hypothesis of subglacial rivers offers fewest difficulties; but more probably they may be relics of beds of rivers of melting ice and snow in the later part of the Glacial Epoch. "Drumlins" are also treated of; described by others as large longitudinal mounds of clay and stones. They are probably of subglacial origin (that is, *under glaciers*).

Both the merely local and the more continuous evidences of ice-action in Britain are succinctly noticed (pp. 120–192), including the Boulder-clay, lower and upper, and the intermediate Glacial Sands and Gravels, especially of Norfolk, Yorkshire, the Midlands, Cheshire, and Moel Tryfaen—also of Suffolk, Essex, and Middlesex. The distribution of boulders from four main centres of dispersion is carefully detailed. The proofs of glaciation in Scotland and Ireland are considered (pp. 192–205), like those in England and Wales, with

reference to their probable causes, in the light of what is known (and brought forward as facts in the foregoing chapters of the book) of the conditions under which ice covers and acts on mountains, plains, and valleys in other parts of the world.

Based on the inferences drawn from facts, two kinds of explanation have been offered; one referring to *Land-ice* on the large scale, the other to *Submergence* and Floating ice. The value of and objections to each hypothesis are carefully and conscientiously stated. The objections to the extreme *Land-ice* hypothesis are apparently the less easy of removal.

Ice-work in Europe and other parts of the world; the possible causes of a Glacial Epoch (its low temperature has not yet been satisfactorily accounted for); the number of Glacial Epochs that may have occurred (the author thinks it probable that only once before the Pleistocene, that is in Carbo-Permian times, such a prevalence of Glacial conditions occurred) — also receive due attention.

The last chapter (pp. 270-284) reviews the main facts concerning ice and glacial deposits, and the general principles of interpretation; and would be well worth reproducing here, but much of it is represented in what goes before. Dr. Bonney wisely concludes that more information is still required, and especially of the effects, habits, and physical properties of large masses of *Polar* ice; but he believes "that enough has been already ascertained to enable the student to distinguish how far an hypothesis is an *induction from facts*, and how far it is an offspring of the imagination."

II.—The Geology and Scenery of Sutherland. By H. M. Cadell, of Grange, B.Sc., F.R.S.E., F.G.S., etc. Second Edition. 8vo, pp. 108, with 8 full-page and 13 smaller illustrations, and 2 maps. (Edinburgh: D. Douglas, 1896.)

THE first edition of this book came out in 1886; since that time new and interesting discoveries have been made by geologists in the North-west Highlands, allowing this new edition to be prepared on a wider basis and with more detail. How greatly the knowledge of the geological structure of a country can benefit the traveller, tourist, and others wandering over hill and dale, for pleasure or duty, has been talked of and written about ever since geology was first really studied. Even now the eyes of many, though educated to recognize the lights and shades, the tints and colours of earth and sky, are blind to the striking evidence *why* the earth presents such various features of heights and flats, of steep cliffs, jagged ridges, and soft slopes, which reflect the phenomena sought for by the artist, but apathetically seen by the multitude.

Scotland is not only a "meet nurse for the poetic child," but has been, and yet will be, the real parent of many geological men and women, who can find pleasure in an intelligent view of her scenery, and enable others to benefit by similar knowledge, both in its æsthetic and more practical advantages. A list of selected books

and memoirs concerning this matter, with reference to Sutherland, is given by Mr. Cadell at pages 15 and 16.

The geology and scenery of North-western Scotland are then described in some detail, with the latest information, and in commonplace language, as far as the subject will allow, the author attempting, more or less successfully, to make it light literature. The foundation-rock or basement is the "old gneiss," composed of crumpled sheets of mineral matter, penetrated throughout by veins of other kinds of rock, relatively harder or softer, that have either filled its cracks or made their way into it.

The history of the "Gneiss" seems to us to be romantic. As with mythic heroes, its origin or parentage is doubtful or unknown. Its record begins with the evidence of the troubles it underwent, overcoming difficulties by giving way to them, and becoming self-consistent and harder (fig. opposite p. 36). So it presented a tough and jagged surface, which the envious ocean smothered with sand and pebbles (fig. 1, p. 46). Then, Titan-like, it forced its way upwards with the superincumbent burden (fig. 2, p. 47); to be cut down to a level by long wear and tear of the water-world, and again entombed by inimical agencies (fig. 3). At last, within the "to-day" of some millions of our years, it has once more regained its land-level; and now exhibits (in Scrishven, Quinag, Canisp, Suilven, and Coulmore; and along the region from Durness and Eriboll on the north, to Ullapool on the south) evidences of the victory of its persistent upward movement, bearing a load of trophies from its primeval entombments. Fig. 4, p. 48, shows these results of "latest upheaval, tilting, and denudation." The same kind of natural forces which originally folded and crumpled the gneiss, still squeezing both the underlying and the overlying rocks and strata, elevated this region, as also other parts of the earth's crust, by causing undulations and foldings to rise above the general level; and gave them side-movements and lateral thrusts, which broke them into sloping segments and pushed them one over another for a distance of even ten miles. The pressure of the displaced rock-masses one on another, along the planes of the thrusts, has ground down their surfaces into material differing from the original—now fragmentary and granular, and yet not due to any deposition in water.

These violent changes in position and substance of the rocks confused the early observers, and were very gradually realized, and only of late elucidated, by many enthusiastic geologists giving time and labour, for pleasure or duty, among the wild highlands of Sutherland.

An interesting chapter (pp. 68–76) details the circumstances under which the author carried on some experiments, with alternating layers of stucco-powder or foundry-loam and of damp sand, squeezed horizontally in a suitable press-box. A succession of obliquely faulted segments of one band, riding one over another at the *point d'appui* in the box, agreeably represented the structure of Arkle or Creag Dionard. Another series of such thrusts on a small

scale, sliding along the base band, itself traversed by long oblique faults, represented Glasven in miniature. In other experiments the mass of faulted bands tended to curve forwards and downwards on and beyond the faulted basement, thus giving "an elementary model of parts of Ben More, Brebag, Ben Thuarain, and other mountains" (p. 74). The probable behaviour of the earth's internal mass under the regions of such faults and thrusts is considered, with reference to another experiment (fig. 11).

The schists, eruptive rocks, and Old Red Sandstone of the rest of Sutherland, also the remaining evidences of the Great Ice Age, and the relics of Jurassic strata and coal at Brora, are succinctly treated. The interesting but not very productive gold-field of Sutherland has a short chapter (pp. 95–103).

The excellent illustrations of the local "bens" and glens, and the two good maps, add much value to the book. One map gives the relative height of the land; and the other deals with the geological structure. It has a careful diagrammatic section of the strata from Cape Wrath to the border of Caithness; and a useful diagram showing the successive stages of rocks and strata, with their unconformities, displacements, and intrusions.

The information given in this little book on Sutherlandshire, brought together by a well-informed, enthusiastic, and trustworthy geologist, and not easily accessible otherwise, will be very useful to geologists at home or in the field; and ought to be in the hands of tourists, whether artist, sportsman, yachtsman, or idler.

REPORTS AND PROCEEDINGS.

Geological Society of London.

I.—February 26th, 1896.—Dr. Henry Hicks, F.R.S., President, in the Chair. The following communications were read:—

1. "On the Structure of the Plesiosaurian Skull." By Charles W. Andrews, Esq., B.Sc., F.G.S.

Owing to the imperfection of the specimens described, various previous accounts of the Plesiosaurian skull are incomplete, and differ from one another in important particulars. There is in the National Collection a fine skull of *Plesiosaurus macrocephalus* which has lately been cleared from the matrix, with a description of which the present communication is mainly occupied, though other specimens, which are of assistance in clearing up some difficulties, are also noticed. The author particularly considers the structure of the palate, and only such points in the structure of the rest of the skull as add to or are at variance with previous descriptions are considered.

The author's observations indicate that a general similarity of palatal structure among reptiles does not necessarily imply any close relationship; but the very great resemblances existing between the Plesiosaurian and Rhynchocephalian palates, reinforced by

numerous other points of resemblance in these skeletons noted by Baur, lead to the conclusion that the Plesiosauria are descended from a primitive Rhynchocephalian reptile, as already opined by Baur, Boulenger, and others.

2. "On certain Granophyres, modified by the Incorporation of Gabbro Fragments, in Strath (Skye)." By Alfred Harker, Esq., M.A., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

The rocks described form a group of irregular intrusions, the largest less than a mile in length, situated in the tract of volcanic agglomerate north and west of Loch Kilchrist. They differ from the normal granophyres, abundantly developed in the neighbourhood, in being darker, denser, and manifestly richer in the iron-bearing minerals, while in places are seen numerous small rock-fragments evidently of extraneous origin.

The fragments are mainly of gabbro. Closer examination shows that they have been abundantly distributed through the granophyre, but most of them have been more or less completely dissolved. The clearest evidence of this is afforded by the augite of the gabbro, which has been less readily attacked by the magma than the other minerals, and is seen in isolated crystals in various stages of conversion to hornblende. The material dissolved has rendered the acid magma less acid, and has influenced accordingly the products of final consolidation. The granophyre is roughly estimated to have taken up about one-fourth of its mass of gabbro, and this material has been derived, not from the rocks seen in contact with the intrusions, but from some subterranean source.

3. "Observations on the Geology of the Nile Valley, and on the Evidence of the greater Volume of that River at a former Period." By Prof. E. Hull, M.A., LL.D., F.R.S., F.G.S.

The author draws attention to the two great periods of erosion of the Nile Valley—the first during the Miocene period, after the elevation of the Libyan region at the close of Eocene times, and the second during a "pluvial" period extending from late Pliocene times into and including the Pleistocene. He notes the course of the river through escarpments of the granitic and schistose rocks of Assuan, the Nubian Sandstone, the Cretaceous limestone, and the Eocene limestone; and observes that in places the line of erosion of the primeval Nile was directed by dislocations of the strata. Evidence of the unconformity of the Nubian Sandstone upon the granites and schists of Assuan is given, and some observations made upon the age of the different parts of the Nubian Sandstone.

In the second part of the paper the terraces of the Nile Valley are described, and full details given of the characters of a second terrace, at a height varying from 50 to 100 feet above the lower one, which is flooded at the present day. The second terrace is devoid of vegetation, and its deposits have frequently furnished river-shells such as *Cyrena fluminalis*, *Ætheria seminulata*, *Unio*, *Paludina*, etc. The second terrace is traceable at intervals for a distance of between 600 and 700 miles above Cairo. Two old

river-channels are also described—one at Koru Ombo, and the other at Assuan itself. The author discusses the mode of origin of the second terrace and the old river-valleys, and believes them to be due to the former greater volume of the river, and not to subsequent erosion of the valley. He gives further evidence of the existence of meteorological conditions sufficient to give rise to a "pluvial" period, and points out that other authors have also considered that the volume of the Nile has been greater in former times.

4. "The Fauna of the Keisley Limestone.—Part I." By F. R. Cowper Reed, Esq., M.A., F.G.S.

The author has examined a very full series of fossils from the Keisley Limestone of Westmoreland, and proposes to describe the fauna of the limestone. In this (first) part of the paper a description of the trilobites is given. He recognizes about forty species, belonging to ten families. Several of the forms are new, whilst others have previously been described, and many of them occur in the limestone of the Chair of Kildare and the *Leptæna*-limestone of Dalecarlia.

II.—March 11th, 1896.—Dr. Henry Hicks, F.R.S., President, in the Chair.

The President announced that, in connection with the Hungarian Millennial Exhibition, a Congress of Mining and Geology would be held at Budapest on September 25th and 26th, 1896.

The following communications were read:—

1. "On an Alpine Nickel-bearing Serpentine with Fulgurites." By Miss E. Aston, B.Sc. With Petrographical Notes by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

The specimens described were collected on the summit of the Riffelhorn (near Zermatt) by Prof. W. Ramsay, F.R.S., and J. Eccles, Esq., F.G.S. As they showed some very well-marked "lightning-tubes," the former thought that possibly analyses might prove interesting. These were undertaken by Miss Aston at University College, London. The rock is a serpentine, somewhat schistose from pressure, which has been formed by the alteration of a rock chiefly composed of olivine and augite. One of the analyses gives 4·92 per cent. of nickel oxide and hardly any lime. Prof. Bonney detected some awaruite under the microscope, but not nearly enough to account for the analysis. Reasons are given to show that the nickel oxide probably replaced lime in the pyroxenic constituent of the rock.

The tubes, about $\frac{1}{10}$ inch in diameter, are round in section, cleanly drilled, and lined with a very thin film of dark-brown or black glass. The microscopic structure of this is described, as well as that of glass made by melting the rock with a blow-pipe (using oxygen). Some fulgurite-glass from the Hörnli has also been examined (much resembling that described by Mr. Rutley from Monte Viso), and an analysis of this rock is given.

2. "The Pliocene Glaciation, Pre-Glacial Valleys, and Lake-Basins of Subalpine Switzerland; with a Note on the Microscopic

Structure of Tavayanaz Diabasic Tufa." By C. S. Du Riche Preller, M.A., Ph.D., F.G.S., F.C.S., A.I.M.I.E., M.I.E.E.

(1) The main object of this paper, which is the sequel to one read last session, was to solve the problem whether the Pliocene glacio-fluviatile conglomerates of the Swiss lowlands were deposited on a plateau or in already existing valleys. For the purpose of this inquiry, the author examined last summer a large additional number of glacial high- and low-level deposits throughout the Zürich Valley, over an area more than 40 miles in length; and his investigations further led him to important conclusions with respect to the combination of causes which determined the formation of the lake-basins lying in the same zone at the foot of the Alps.

(2) The author established the true characteristics of the Pliocene nagelfluh as distinguished from Miocene—purely fluviatile conglomerate on the one hand, and from glacio-fluviatile Pleistocene gravels on the other. With respect to the origin of the Pliocene conglomerate, he contended that the material composing the same was not transported from a great distance, but was, in the main, derived from the enormous accumulations of Miocene nagelfluh at the foot of the Alps. Specimens of Miocene nagelfluh-pebbles were exhibited, including the so-called "Tavayanaz Sandstone," which the author, in an appendix to the paper, showed to be diabasic tufa.

(3) The author described in detail a variety of glacial exposures, and showed that Pliocene nagelfluh *in situ*, of which he exhibited numerous specimens, occurred not only on the ridges of the hills, but, at a gradually ascending level, also at and near the floor of the Zürich Valley.

Hence he contended that at the advent of the first glaciation the Zürich Valley was already eroded, and that, consequently, the term "Dechenschotter," or plateau-gravel, was not strictly applicable to the Pliocene glacio-fluviatile deposits of the Swiss lowlands. In his view, the isolated high-level deposits were formed during the intermittent shrinkage of the Upper Pliocene ice-sheet, while the low-level deposits were formed during the subsequent recession of individual glaciers left in the several valleys.

(4) The author reconstructed the pre-Glacial floor of the Zürich Valley upon the evidence of the solid rock and of the low-level Pliocene nagelfluh deposits, with the result that the depth of the lower part of the Valley was approximately that of the present day, while the floor of the upper part was at a higher level (maximum, 300 feet above present lake-level), and was subsequently lowered by earth-movements. He further adduced evidence that the Subalpine valleys of the Reuss, Aare, and Rhine were likewise excavated before the first glaciation. By calculation, he arrived at an estimate of the time required for the excavation of the Zürich Valley, and contrasted the erosive energy of the river with the impotence, on mechanical grounds, of a glacier 7000 times larger in volume.

(5) The author showed that the Lake of Zürich owes its origin, in the first instance, to a zonal subsidence (probably between the first and second glaciation) of about 1000 feet, as evidenced by the

reversed dip of the disturbed molasse-strata between the lakes of Zürich and Zug. During the second and third Ice-periods, the original lake-basin was gradually filled with glacial and fluviatile deposits at both ends, and was finally restricted to its present dimensions by a post-Glacial bar deposited at its lower end by a tributary river. In the author's view, the other Subalpine lakes, extending from the Lake of Constance to Lac Bourget in Savoy, owe their origin and present limits, in the main, to the operation of similar causes.

(6) With regard to the main question, the author averred that the Lower and Middle Pliocene period was, in Switzerland, entirely one of erosion and denudation on a prodigious scale. Irrespective of the evidence he had adduced, he was therefore driven to the conclusion that at the advent of the first Ice-period in Upper Pliocene times, the principal Subalpine valleys must have been already excavated approximately to their present depth; and that ever since then the action of the great Alpine and Subalpine rivers has been, as it is still in our own day, mainly directed to regaining the old valley-floors by removing those enormous accumulations of glacial and glacio-fluviatile material, which are respectively the direct and indirect products of three successive and general glaciations.

3. "Notes concerning certain Linear Marks in a Sedimentary Rock." By Prof. J. E. Talmage, D.Sc., F.G.S.

The marks described in the paper occur in a fine-grained argillaceous sandstone referred by the U.S. Geological Survey to the Triassic or Jura-Trias period, which is found on a low tableland within two miles of the bluffs overlooking Glen Canyon. The marks commonly appear as straight lines intersecting at right angles, but some have a pinnate distribution, suggesting engravings of frost-flowers. A description of the markings is given; and various experiments made in the laboratory to illustrate the effects of formation of crystals formed over sediment are described.

III.—March 25th, 1896.—Dr. Henry Hicks, F.R.S., President, in the Chair. The following communications were read:—

1. "On Submerged Land-surfaces at Barry, Glamorganshire." By A. Strahan, Esq., M.A., F.G.S. With Notes on the Fauna and Flora by Clement Reid, Esq., F.L.S., F.G.S., and an Appendix on the Microzoa by Prof. T. Rupert Jones, F.R.S., F.G.S., and F. Chapman, Esq., F.R.M.S. (Communicated by permission of the Director-General of H.M. Geological Survey.)

Excavations for a new dock at Barry have disclosed a series of fresh-water or slightly estuarine silts with intercalated peats, below sea-level on the north-eastern side of the island. The site of the excavation was overflowed by the tide until the year 1884, when the docks were commenced. The newest deposits seen are therefore Blown Sand, *Scrobicularia*-clay, and sand or shingle with recent marine shells.

These rest on an eroded surface of blue silt, with sedges in

position of growth. Four peat-beds occur in this silt, at 4, 11, 20, and 35 feet below Ordnance datum respectively. The uppermost peat contains a seam of shell-marl, partly composed of the shells of ostracoda and partly of *Bythinia*, *Limnæa*, etc. The second is a mass of matted sedges. The third is a land-surface, and in places consists almost wholly of timber with the stools and roots *in situ*. The fourth is also an old land-surface, as is proved not only by the presence of roots in place beneath it, but by numerous land-shells. A fragment of a polished flint-celt was found by Mr. Storrie imbedded in the lower part of the uppermost peat.

By a comparison with the existing maritime marshes of the neighbourhood, it is shown that the fourth peat indicates a subsidence of not less than 55 feet.

The sea encroached upon the area in consequence of this subsidence. It entered by the lowest of three low cols in the southern water-parting of the Cadoxton river, thus isolating the portion of land now known as Barry Island. A slight further movement would have converted the water-parting into a chain of islands.

2. "On a Phosphatic Chalk with *Holaster planus* at Lewes." By A. Strahan, Esq., M.A., F.G.S. With an Appendix on the Ostracoda and Foraminifera by F. Chapman, Esq., F.R.M.S. (Communicated by permission of the Director-General of H.M. Geological Survey.)

This rock, which occurs at the base of the Upper Chalk, at the horizon of the Chalk Rock, does not exceed 1½ foot in thickness, and persists for a few yards only. In composition and microscopic character it presents a close analogy to the Taplow phosphatic deposit, which, however, occurs at the top of the Upper Chalk. Like it, it consists of brown phosphatic grains imbedded in a white chalky matrix. The grains include a large number of pellets, attributable to small fish, phosphatized foraminifera, chips of bone, etc. Fish-teeth also occur in abundance.

To complete the resemblance, the Lewes deposit rests on a floor of hard nodular chalk, beneath which is a white chalk traversed by irregular branching pipes filled with the brown variety. Such "floors" are attributed to concretionary action ensuing upon a pause in the sedimentation. The piped chalk is compared with the structure known as *Spongia paradoxica*.

It is concluded that phosphatized deposits may occur at any horizon in the Chalk; that the phosphatization is due to small fishes, attracted by an unusual abundance of food; that they are shallow-water deposits, and associated with a pause or change in the sedimentation.

Mr. Chapman furnishes a list of 42 species and varieties of Foraminifera and 6 species of Ostracoda. The former indicate a deeper water origin than do those of the Taplow Chalk. He notes the occurrence for the first time in this country of *Gypsina Coetæ*, Marrson.

3. "On the Classification of the Strata between the Kimeridgian and the Aptian." By Dr. A. P. Pavlow, Professor of Geology in the University of Moscow, For. Corr. G.S.

In this paper the author discusses the new evidence respecting the palæontology of the Lower Cretaceous and Upper Jurassic deposits of Russia which has come to light since the publication by himself and Mr. Lamplugh of "Les Argiles de Speeton et leurs Équivalents" (Moscow, 1892). He is now enabled to fix with certainty the zones of *Hoplites Riasensis* and *Olcostephanus hoplitoides* of the provinces of Riasan and Simbirsk, and is thus in a position to correct and complete his former classification of the Upper Jurassic and Lower Cretaceous rocks of Russia, and to define more strictly their relationship to the equivalent strata of other countries.

The whole of the Petchorian Series—that is, the zones of *Ammonites stenomphalus* and *Amm. Keyserlingi*—is now regarded as Lower Neocomian of a hitherto unknown boreal type, notwithstanding the affinity of its fauna with that of the underlying Jurassic (Aquilonian) strata. The author is thus led to carry up into the Cretaceous the corresponding stages in Western Europe, including the upper part of the zone of *Belemnites lateralis* of Speeton and Lincolnshire, the Upper Berriasian of South-eastern France, and probably the Hils Beds of Germany, instead of classing these with the Jurassic as he had previously done.

A table is given in which the detailed correlation of the rocks between the Kimeridgian and the Aptian of the various regions is attempted.

The comparison of the beds of England and Germany with those of Russia is supported by some new evidence based on the *Aucellæ*, four species of which are described as occurring in the Claxby Ironstone and Spilsby Sandstone of Lincolnshire.

In conclusion, the author shows that in the period under consideration the shore-lines of Europe have been shifted by slow progressive movements passing latitudinally through the region, and that these movements did not affect the whole area simultaneously. Hence many complicated interchanges of fauna were brought about, which can only be unravelled by studying the whole course of events over wide areas.

OBITUARY.

HON. WALTER BALDOCK D. MANTELL, F.G.S.

Born in 1820. Died Sept. 7th, 1895.

The Hon. Walter Baldock Durrant Mantell, F.G.S., was the eldest son of Dr. Gideon Mantell, F.R.S., F.G.S., the well-known Sussex geologist and discoverer of the Iguanodon. He was born in 1820, and left England for New Zealand about 1840, where he became a man of great public importance, holding the posts of Minister for Native Affairs, Postmaster-General, and Secretary for Crown Lands. He was ever mindful of the interests of the Maoris, and sought to serve them to the utmost of his power.

In 1847 Mr. Mantell sent home the first remains of *Notornis*. These were described by Owen as belonging to an extinct form; but two years later, in 1849, Mantell obtained from some sealers on the

south coast of Middle Island (now called the South Island, where he was Government Commissioner for the Settlement of Native Claims) a skin, together with the skull and some limb-bones, of a *Notornis* recently hunted down with dogs, and killed and eaten by these men. Not long afterwards another smaller skin was obtained. Both these specimens are preserved in the Natural History Museum.

The bird was apparently unknown to the Maoris, but there are traditions of a "Swamp-Hen," called on the North Island *Moho*, and in the South *Takahé*, which may have been the *Notornis*.

In 1868 Mantell read a paper before the New Zealand Institute[1] "On the Moa," in which he insisted that these birds were contemporaries of man, their remains being found charred and broken in the Maori ovens, together with stone implements. He also discussed the cause of the extinction of the Moa, and ascribed it chiefly to the agency of man, a view now generally accepted.

In a later paper read before the Wellington Philosophical Society, 1872, he discusses statements that had been made, that Moa-bones had been found beneath marine deposits with extinct shells; and states that this idea arose from a misapprehension of some information supplied by him to his father, who employed it in his paper before the Geological Society.[2] He also gave an account of some new localities in which Moa-remains had been found, including Waikonaiti and Te-Rangatapu. In the latter he obtained a large number of fragments of Moa eggs, several of which he succeeded in restoring. Some of these specimens are now in the Natural History Museum.[3]

Mr. Mantell was elected a Fellow of the Geological Society in 1858. He died on September 7th, 1895, at the age of 75 years. He was in correspondence with Sir William Flower at the time of his death, as to a further donation of his remaining private collection of Moa-remains to the British Museum, which it is hoped may still be made by his representatives at Wellington, New Zealand.

MISCELLANEOUS.

Geological Survey.—We learn that Mr. J. R. Dakyns, M.A., who joined the Geological Survey in 1862, has just retired from the Service. Mr. A. Strahan, M.A., has been promoted to the rank of Geologist on the English branch of the Survey, and Mr. C. T. Clough, M.A., is similarly promoted on the Scottish branch (in the room of the late Hugh Miller). The two vacancies on the Staff of Assistant Geologists are filled by the appointment of Mr. T. Crosbee Cantrill, B.Sc., in England, and of Mr. E. H. Cunningham-Craig in Scotland.

[1] Trans. New Zealand Institute, vol. i, 1868.

[2] See Quart. Journ. Geol. Soc., Feb. 2nd and 22nd, 1848, vol. iv, pp. 225–241. [The woodcut which gave rise to the misapprehension is probably that on p. 240.]

[3] See Notice of the Remains of *Dinornis* and other Birds, and of Fossils and Rock-specimens, recently collected by Mr. Walter Mantell in the Middle Island of New Zealand. By G. A. Mantell. With Notes by E. Forbes, and Sketch-map and Notes by Walter Mantell. Quart. Journ. Geol. Soc., vi (1850), p. 319.